PHYSIOLOGY

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LESSONS

IN

ELEMENTARY PHYSIOLOGY

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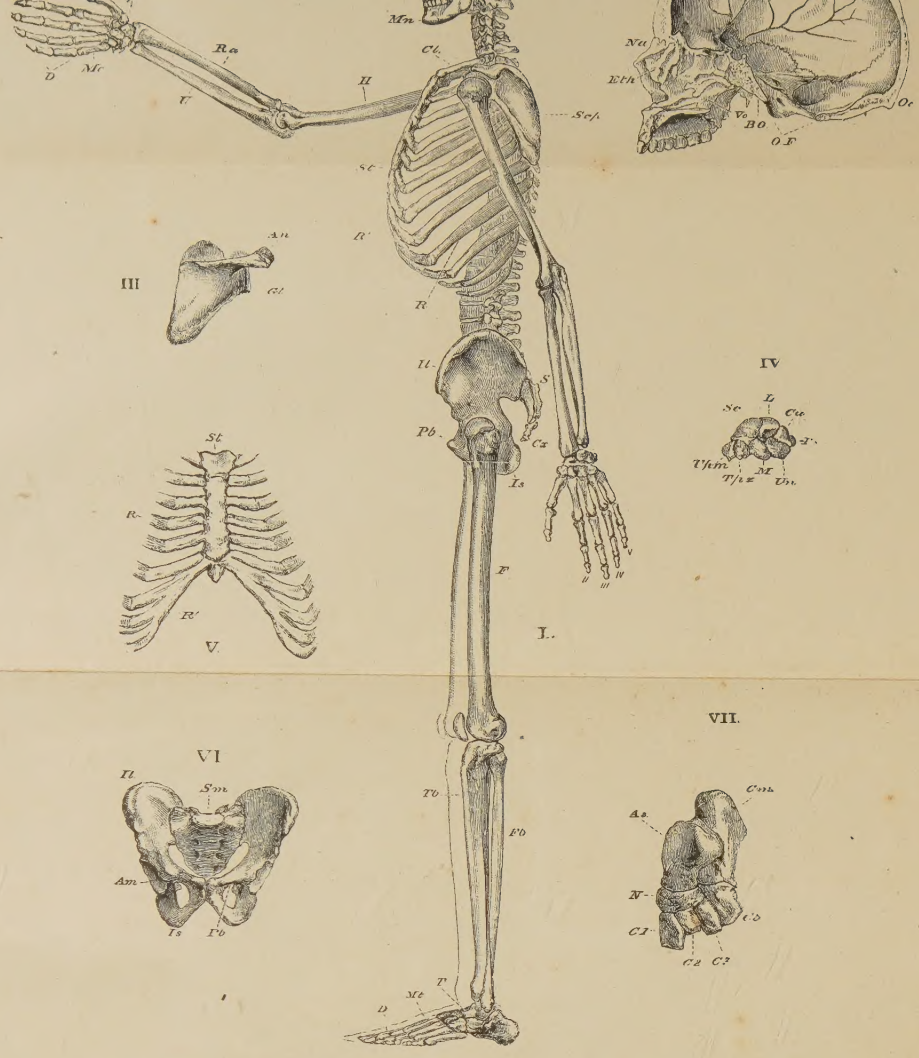

EXPLANATION OF THE PLATE.

FIG. I.—THE HUMAN SKELETON IN PROFILE

Na. The Nasal bones.
Fr. The Frontal bone.
Pa. The Parietal bones.
Oc. The Occipital bone.
Mn. The Mandible, or Lower Jaw.
} In the Skull.

St. The Sternum.
R. The Ribs.
R'. The Cartilages of the Ribs.
} In the Thorax.

S. The Sacrum.
Cx. The Coccyx.
Scp. The Scapula, or Shoulder Blade.
Cl. The Clavicle, or Collar Bone.
H. The Humerus.
Ra The Radius.
U. The Ulna.
Cp. The Carpus.
} In the Arm.

Mc. The Metacarpus.
D. The Phalanges of the Fingers or Digits of the Hand.
} In the Arm.

I, II, III, IV, V. The Thumb, or Pollex, and the succeeding Fingers.

Il. The Ilium.
Pb. The Pubis.
Is. The Ischium.
} Which together form the Haunch bone, or Os innominatum.

F. The Femur.
Tb. The Tibia.
Fb. The Fibula.
T. The Tarsus.
Mt. The Metatarsus.
D. The Phalanges of the Toes, or Digits of the Foot.
} In the Leg.

FIG. II.—LONGITUDINAL AND VERTICAL SECTION OF THE SKULL.

The section passes a little to the left of the middle line.

The letters as before, except—
Eth. The Ethmoid bone.
Vo. The Vomer.
B.O. Part of the Occipital bone.
O.F. The Occipital Foramen.

The branching lines are the impressions left by the arteries of the membranes of the brain upon the inner surface of the wall of the cavity, which lodges the cerebrum.

FIG. III.—THE RIGHT SCAPULA.

An. Acromion process.
Gl. Glenoidal cavity.

FIG IV.—THE DORSAL ASPECT OF THE BONES OF THE CARPUS OF THE LEFT HAND.

Sc. Scaphoides.
Tpm. Trapezium.
L. Semilunare.
Tpz. Trapezoides.
Cu. Cuneiforme.
M. Magnum.
Ps. Pisiforme.
Un. Unciforme.

FIG. V.

A front view of the Sternum, *St.*, with the Cartilages of the Ribs, *R'*, and the part of Ribs themselves, *R.*

FIG. VI.—A FRONT VIEW OF THE PELVIS.

Sm. The Sacrum.
Am. The Acetabulum
Il. Pb. Is as before

FIG. VII.—THE DORSAL ASPECT OF THE TARSUS OF THE LEFT FOOT.

Cm. Calcaneum.
As. Astragalus.
N. Naviculare.
C1, C2, C3. The three Cuneiform bones.
Cb. The Cuboid.

100/2 ORPINGTON DIVISION

LESSONS

IN ELEMENTARY

PHYSIOLOGY

BY

THOMAS H. HUXLEY, LL.D., F.R.S.

ENLARGED AND REVISED EDITION

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PREFACE

My friend Dr. Lea and I have undertaken a task of great difficulty.

The progress which has taken place in science and in education since the last revision of this work has rendered it desirable to make considerable changes and additions in order to maintain for the book the usefulness which has been for so long a time its conspicuous feature.

At the same time a pious feeling has led us to preserve as far as possible the original author's own form of exposition, and indeed his own words. We have done our best to secure both of these ends.

Although I share with Dr. Lea the responsibility of all the changes which have been made, the main labour has fallen on him; and I may say that both his larger and my smaller share in the work have

been truly labours of love, small tributes of affection to the master who is no more.

We take this opportunity of expressing our thanks to Professor Schäfer for permission to copy several figures in *Quain's Anatomy*; to Mr. W. B. Hardy for his help in reading the whole book in proof, and in preparing many of the new figures; and to Dr. W. H. Rivers for revising the proofs of Lessons VIII., IX. and X.

M. FOSTER.

September, 1899.

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LESSONS

IN

ELEMENTARY PHYSIOLOGY

A COMPARISON OF CERTAIN BRITISH AND METRIC UNITS.

Thermometric.

Centigrade.	Fahrenheit.
0	32
5	41
10	50
15	59
20	68
25	77
30	86
35	95
36	96·8
37	98·6
38	100·4
39	102·2
40	104
41	105·8
42	107·6
43	109·4
44	111·2
45	113
55	131
65	149
75	167
85	185
95	203
100	212

Length ...
- 1 meter (m.) = 1000 millimeters (mm.).
- = 100 centimeters (cm.) = 39·37 inches.
- 1 inch = 25·4 millimeters.
- 1 foot = 30·4 centimeters.
- $\mu = \frac{1}{1000}$ millimeter = $\frac{1}{25000}$ inch (nearly).

Weight ...
- 1 kilogramme (kg.) = 1000 grammes (g.) = 2·2 lbs. Avoir.
- 1 gramme (g.) = 1000 milligrammes (mg.) = 15·4 grains.
- 1 pound (Avoir.) = 453·6 grammes, or about $\frac{1}{2}$ kilogramme.
- 1 ounce ,, = 28·35 grammes = 437·5 grains.

Capacity..
- 1 litre (l.) = 1000 cubic centimeters (c.c.) = 1·76 pint.
- 1 fluid ounce = 28·4 cubic centimeters.
- 1 pint = 20 fluid oz. = 567·5 cubic centimeters.
- 1 gallon = 4·54 litres.
- 1 cubic inch = 16·38 cubic centimeters
- 1 cubic foot = 28·3 litres.

Work .....
- 1 kilogramme-meter (kg.m.) = 7·25 foot-pounds
- 1 foot-pound = ·138 kilogramme-meter.
- 1 foot-ton = 310 kilogramme-meters.

Heat .....
- (British) 1 unit of heat = heat necessary to raise 1 pound of water through 1° F.
- (Metric) 1 calorie = ,, ,, ,, ,, 1 gramme ,, 1° C.
- Mechanical equivalent of heat unit = 772 foot-pounds.
- ,, ,, ,, calorie = 424 gramme-meters.

LESSONS

IN

ELEMENTARY PHYSIOLOGY

LESSON I

A GENERAL VIEW OF THE STRUCTURE AND FUNCTIONS OF THE HUMAN BODY

1. The Work of the Body as a whole.—The body of a living man performs a great diversity of actions, some of which are quite obvious; others require more or less careful observation; and yet others can be detected only by the employment of the most delicate appliances of science.

Thus, some part of the body of a living man is plainly always in motion. Even in sleep, when the limbs, head, and eyelids may be still, the incessant rise and fall of the chest continue to remind us that we are viewing slumber and not death.

More careful observation, however, is needed to detect the motion of the heart; or the pulsation of the arteries; or the changes in the size of the pupil of the eye with varying light; or to ascertain that the air which is breathed

out of the body is hotter and damper than the air which is taken in by breathing.

And lastly; when we try to ascertain what happens in the eye when that organ is adjusted to different distances; or what in a nerve when it is excited: or of what materials flesh and blood are made: or in virtue of what mechanism it is that a sudden pain makes one start—we have to call into operation all the methods of inductive and deductive logic; all the resources of physics and chemistry; and all the delicacies of the art of experiment.

The sum of the facts and generalizations at which we arrive by these various modes of inquiry, be they simple or be they refined, concerning the actions of the body and the manner in which those actions are brought about, constitutes the science of Human Physiology. An elementary outline of this science, and of so much anatomy as is incidentally necessary, is the subject of the following Lessons; of which we shall devote the present to an account of so much of the structure and such of the actions (or, as they are technically called, "functions") of the body, as can be ascertained by easy observation; or might be so ascertained if the bodies of men were as easily procured, examined, and subjected to experiment, as those of animals.

Suppose a chamber with walls of ice, through which a current of pure ice-cold air passes; the walls of the chamber will of course remain unmelted.

Now, having weighed a healthy living man with great care, let him walk up and down the chamber for an hour. In doing this he will obviously do a considerable amount of work and use up a proportionate quantity of energy; as much, at least, as would be required to lift his weight as high and as often as he has raised himself at every step. But, in addition, a certain quantity of the ice will be melted, or converted into water; showing that the man has given off heat in abundance. Furthermore, if the air which enters the chamber be made to pass through lime-water, it will cause no cloudy white precipitate of car-

bonate of lime, because the quantity of carbonic acid[1] in ordinary air is so small as to be inappreciable in this way. But if the air which passes out is made to take the same course, the lime-water will soon become milky, from the precipitation of carbonate of lime, showing the presence of carbonic acid, which, like the heat, is given off by the man.

Again, even if the air be quite dry as it enters the chamber (and the chamber be lined with some material so as to shut out all vapour from the melting ice walls), that which is breathed out of the man, and that which is given off from his skin, will exhibit clouds of vapour ; which vapour, therefore, is derived from the body.

After the expiration of the hour during which the experiment has lasted, let the man be released and weighed once more. He will be found to have lost weight.

Thus a living, active man, constantly does **mechanical work**, gives off **heat**, evolves **carbonic acid** and **water**, and undergoes a **loss of substance.**

Plainly, this state of things could not continue for an unlimited period, or the man would dwindle to nothing. But long before the effects of this gradual diminution of substance become apparent to a bystander, they are felt by the subject of the experiment in the form of the two imperious sensations called hunger and thirst. To still these cravings, to restore the weight of the body to its former amount, to enable it to continue giving out heat, water, and carbonic acid, at the same rate, for an indefinite period, it is absolutely necessary that the body should be supplied with each of three things, and with three only. These are, firstly, fresh air ; secondly, drink—consisting of water in some shape or other, however much it may be adulterated ; thirdly, food. That compound known to

[1] By "carbonic acid" we mean "carbonic acid gas." This should in strictness be called carbon dioxide (CO_2), carbonic acid being the compound of this with water, H_2CO_3. But for simplicity's sake, and because the expression "carbonic acid" is in general use and is generally understood to stand for carbon dioxide, we shall use it throughout this book.

chemists as **proteid** matter (Lesson III.), and which contains carbon, hydrogen, oxygen, and nitrogen, must form a part of this food, if it is to sustain life indefinitely ; and fatty, starchy, or saccharine, *i.e.* carbohydrate matters, together with a certain amount of salts, ought to be contained in the food, if it is to sustain life conveniently.

A certain proportion of the matter taken in as food either cannot be, or at any rate is not, used ; and leaves the body, as *excrementitious matter*, having simply passed through the alimentary canal without undergoing much change, and without ever being incorporated into the actual substance of the body. But, under healthy conditions, and when only so much food as is necessary is taken, no important proportion of either proteid matter, or fat, or starchy or saccharine food, passes out of the body as such. Almost all real food ultimately leaves the body as waste in the form either of **water**, or of **carbonic acid**, or of a third substance called **urea**, or of certain saline compounds or **salts**.

Chemists have determined that these products which are thrown out of the body and are called **excretions**, contain if taken altogether, far more oxygen than the food and water taken into the body. Now, the only possible source whence the body can obtain oxygen, except from food and water, is the air which surrounds it.[1] And careful investigation of the air which leaves the chamber in the imaginary experiment described above would show, not only that it has gained carbonic acid *from* the man, but that it has lost *oxygen* in equal or rather greater amount *to* him.

Thus, if a man is neither gaining nor losing weight, the sum of the weights of all the substances above enumerated which leave the body ought to be exactly equal to the

[1] Fresh country air contains in every 100 parts nearly 21 of oxygen and 79 of nitrogen gas, together with a small fraction of a part (·04) of carbonic acid, and a variable quantity of watery vapour. The recently discovered constituent of the atmosphere, argon, is here reckoned in with the nitrogen. (See Lesson IV.)

weight of the food and water which enter it, together with that of the oxygen which it absorbs from the air. And this is proved to be the case.

Hence it follows that a man in health, and "neither gaining nor losing flesh," is *incessantly* oxidating and wasting away, and *periodically* making good the loss. So that if, in his average condition, he could be confined in the scale-pan of a delicate spring balance, like that used for weighing letters, the scale-pan would descend at every meal, and ascend in the intervals, oscillating to equal distances on each side of the average position, which would never be maintained for longer than a few minutes. There is, therefore, no such thing as a stationary condition of the weight of the body, and what we call such is simply a condition of variation within narrow limits—a condition in which the gains and losses of the numerous daily transactions of the economy balance one another.

Suppose this diurnally-balanced physiological state to be reached, it can be maintained only so long as the quantity of the mechanical work done, and of heat, or other force evolved, remains absolutely unchanged.

Let such a physiologically-balanced man lift a heavy body from the ground, and the loss of weight which he would have undergone without that exertion will be increased by a definite amount, which cannot be made good unless a proportionate amount of extra food be supplied to him. Let the temperature of the surrounding air fall, and the same result will occur, if his body remains as warm as before.

On the other hand, diminish his exertion and lower his production of heat, and either he will gain weight, or some of his food will remain unused.

Thus, in a properly nourished man, a stream of food is constantly entering the body in the shape of complex compounds containing comparatively little oxygen; as constantly, the elements of the food (whether before or

after they have formed part of the living substance) are leaving the body, combined with more oxygen. And the incessant breaking down and oxidation of the complex compounds which enter the body are definitely proportioned to the amount of energy the body gives out, whether in the shape of heat or otherwise ; just in the same way as the amount of work to be got out of a steam-engine, and the amount of heat it and its furnace give off, bear a strict proportion to its consumption of fuel.

From these general considerations regarding the nature of life, considered as physiological work, we may turn for the purpose of taking a like broad survey of the apparatus which does the work. We have seen the general performance of the engine, we may now look at its build.

2. **The General Build of the Body.**—The human body is obviously separable into **head**, **trunk**, and **limbs.** In the head, the brain-case or **skull** is distinguishable from the **face**. The trunk is naturally divided into the chest or **thorax**, and the belly or **abdomen.** Of the limbs there are two pairs—the upper, or **arms**, and the lower, or **legs** ; and legs and arms again are subdivided by their joints into parts which obviously exhibit a rough correspondence—**thigh** and **upper arm**, **leg** and **forearm**, **ankle** and **wrist**, **fingers** and **toes**, plainly answering to one another. And the two last, in fact, are so similar that they receive the same name of **digits** ; while the several joints of the fingers and toes have the common denomination of **phalanges.**

The whole body thus composed (without the viscera or organs which fill the cavities of the trunk) is seen to be bilaterally symmetrical ; that is to say, if it were split lengthways by a great knife, which should be made to pass along the middle line of both the dorsal and ventral (or back and front) aspects, the two halves would almost exactly resemble one another.

One-half of the body, divided in the manner described (Fig. 1, A), would exhibit in the trunk, the cut faces of

irty-three bones, joined together by a very strong and ugh substance into a long column, which lies much arer the *dorsal* (or back) than the *ventral* (or front) pect of the body. The bones thus cut through are lled the *bodies* of the **vertebræ**. They separate a ng, narrow canal, called the **spinal canal**, which is ced upon their dorsal side, from the spacious chamber the chest and abdomen, which lies upon their ventral le. There is no direct communication between the rsal canal and the ventral cavity.

The spinal canal contains a long white cord—the **spinal ord**—which is an important part of the nervous system. ie ventral chamber is divided into the two subordinate vities of the thorax and abdomen by a remarkable, rtly fleshy and partly membranous, partition, the **dia-hragm** (Fig. 1, *D*), which is concave towards the abdo-en, and convex towards the thorax. The **alimentary anal** (Fig. 1, *Al.*) traverses these cavities from one end the other, piercing the diaphragm. So does a long uble series of distinct masses of nervous substance, hich are called **ganglia**, are connected together by rvous cords, and constitute the so-called **sympathetic ystem** (Fig. 1, *Sy.*). The abdomen contains, in dition to these parts, the two **kidneys**, one placed ainst each side of the vertebral column and connected ch by a tube, the **ureter**, to a muscular bag, the **adder** lying at the bottom of the abdomen ; the **liver**, e **pancreas** or "sweetbread" and the **spleen**. The orax incloses, besides its segment of the alimentary nal and of the sympathetic, the **heart** and the two ngs. The latter are placed one on each side of the heart, hich lies nearly in the middle of the thorax.

Where the body is succeeded by the head, the upper-ost of the thirty-three vertebral bodies is followed by a ntinuous mass of bone, which extends through the whole ngth of the head, and, like the spinal column, separates dorsal chamber from a ventral one. The dorsal chamber,

or **cavity of the skull**, opens into the spinal canal. It contains a mass of nervous matter called the **brain**, which is continuous with the spinal cord, the brain and the spinal cord together constituting what is termed the **cerebro-spinal system** (Fig. 1, *C.S.*, *C.S.*). The ventral chamber, or **cavity of the face**, is almost entirely occupied by the **mouth** and **pharynx**, into which last the upper end of the alimentary canal (called gullet or **œsophagus**) opens.

Thus, the study of a longitudinal section shows us that the human body is a double tube, the two tubes being completely separated by the spinal column and the bony axis of the skull, which form the floor of the one tube and the roof of the other. The dorsal tube contains the cerebro-spinal axis ; the ventral tube contains the alimentary canal, the sympathetic nervous system, the heart, and the lungs, besides other organs.

Transverse sections, taken perpendicularly to the axis of the vertebral column, or to that of the skull, show still more clearly that this is the fundamental structure of the human body, and that the great apparent difference between the head and the trunk is due to the different size of the dorsal cavity relatively to the ventral. In the head the former cavity is very large in proportion to the size of the latter (Fig. 1, B) ; in the thorax, or abdomen it is very small (Fig. 1, C).

The limbs contain no such chambers as are found in the body and the head ; but with the exception of certain branching tubes filled with fluid, which are called **blood-vessels** and **lymphatics**, are solid or semi-solid, throughout.

3. The Tissues generally.—Such being the general character and arrangement of the parts of the human body, it will next be well to consider into what constituents it may be separated by the aid of no better means of discrimination than the eye and the anatomist's knife.

With no more elaborate aids than these, it becomes

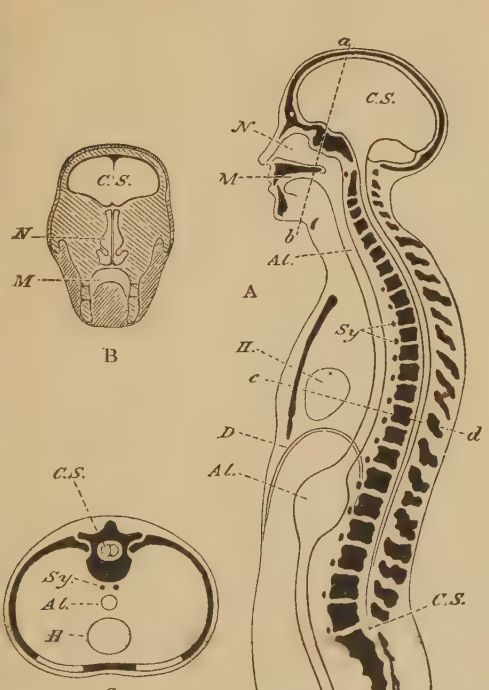


FIG. 1.

A diagrammatic section of the human body taken vertically ough the median plane. *C.S.* the cerebro-spinal nervous system; he cavity of the nose; *M*, that of the mouth; *Al. Al.* the alimentary al represented as a simple straight tube; *H*, the heart; *D*, the dia-agm; *Sy*, the sympathetic ganglia.

A transverse vertical section of the head taken along the line *a b*; ers as before.

A transverse section taken along the line *c d*; letters as before.

easy to separate that tough membrane which invests the whole body, and is called the skin, or **integument**, from the parts which lie beneath it. Furthermore, it is readily enough ascertained that this integument consists of two portions: a superficial layer, which is constantly being shed in the form of powder or scales composed of minute particles of horny matter, and is called the **epidermis**; and the deeper part, the **dermis**, which is dense and fibrous (Lesson V.). The epidermis, if wounded, neither gives rise to pain nor bleeds. The dermis, under like circumstances, is very tender, and bleeds freely. A practical distinction is drawn between the two in shaving, in the course of which operation the razor ought to cut only epidermic structures; for if it go a shade deeper, it gives rise to pain and bleeding.

The skin can be readily enough removed from all parts of the exterior, but at the margins of the apertures of the body it seems to stop, and to be replaced by a layer which is much redder, more sensitive, bleeds more readily, and which keeps itself continually moist by giving out a more or less tenacious fluid, called **mucus**. Hence, at these apertures, the skin is said to stop, and to be replaced by **mucous membrane**, which lines all those interior cavities, such as the alimentary canal, into which the apertures open. But, in truth, the skin does not really come to an end at these points, but is directly continued into the mucous membrane, which last is simply an integument of greater delicacy, but consisting fundamentally of the same two layers—a deep, fibrous layer, containing blood-vessels, and a superficial bloodless one, now called the **epithelium**. Thus every part of the body might be said to be contained between the walls of a double bag, formed by the epidermis, which invests the outside of the body, and the epithelium, its continuation, which lines the alimentary canal.

The dermis, and the deep, sanguine layer, which answers to it in the mucous membranes, are chiefly made up of

amentous substance, which yields abundant **gelatine** being boiled, and is the matter which tans when hide is ne into leather. This is called **connective tissue**,[1] ause it is the great connecting medium by which the erent parts of the body are held together. Thus it ses from the dermis between all the other organs, en- athing the muscles, coating the bones and cartilages, eventually reaching and entering into the mucous nbranes. And so completely and thoroughly does the nective tissue permeate almost all parts of the body, if every other tissue could be dissected away, a com- e model of all the organs would be left composed of this ue. Connective tissue varies very much in character; ome places being very soft and tender, at others—as in tendons and ligaments, which are almost wholly com- ed of it—attaining great strength and density.

Among the most important of the tissues imbedded in ensheathed by the connective tissue, are some the sence and action of which can be readily determined ing life.

If the upper arm of a man whose arm is stretched out tightly grasped by another person, the latter, as the ner bends up his fore-arm, will feel a great soft mass ich lies at the fore part of the upper arm, swell, harden, become prominent. As the arm is extended again, swelling and hardness vanish.

On removing the skin, the body which thus changes its nfiguration is found to be a mass of red flesh, sheathed connective tissue. The sheath is continued at each d into a tendon, by which the muscle is attached, on one hand, to the shoulder-bone, and, on the other, to e of the bones of the fore-arm. This mass of flesh is e **muscle** called *biceps*, and it has the peculiar pro- rty of changing its dimensions—shortening and be- ning thick in proportion to its decrease in length—when

[1] Every such constituent of the body, as epidermis, cartilage, or scle, is called a "tissue." (See Lesson XII.)

influenced by the will as well as by some other causes, called **stimuli**, and of returning to its original form when let alone. This temporary change in the dimensions of a muscle, this shortening and thickening, is spoken of as its **contraction**. It is by reason of this property that muscular tissue becomes the great motor agent of the body; the muscles being so disposed between the systems of levers which support the body, that their contraction necessitates the motion of one lever upon another.

4. The Skeleton.—These levers form part of the system of hard tissues which constitute the **skeleton**. The less hard of these are the **cartilages**, composed of a dense, firm substance, ordinarily known as "gristle." The harder are the **bones**, which are masses of tissue, hardened by being impregnated with **phosphate** and **carbonate of lime**. They are animal tissues which have become, in a manner, naturally petrified; and when the salts of lime are extracted, as they may be, by the action of acids, a model of the bone in soft and flexible animal matter remains.

More than 200 separate bones are ordinarily reckoned in the human body, though the actual number of distinct bones varies at different periods of life, many bones which are separate in youth becoming united together in old age. Thus there are originally, as we have seen, thirty-three separate bodies of vertebræ in the spinal column, and the upper twenty-four of these commonly remain distinct throughout life. But the twenty-fifth, twenty-sixth, twenty-seventh, twenty-eighth, and twenty-ninth early unite into one great bone, called the **sacrum**; and the four remaining vertebræ often run into one bony mass called the **coccyx**.

In early adult life, the skull contains twenty-two naturally separate bones, but in youth the number is much greater, and in old age far less.

Twenty-four ribs bound the chest laterally, twelve on each side, and most of them are connected by cartilages with

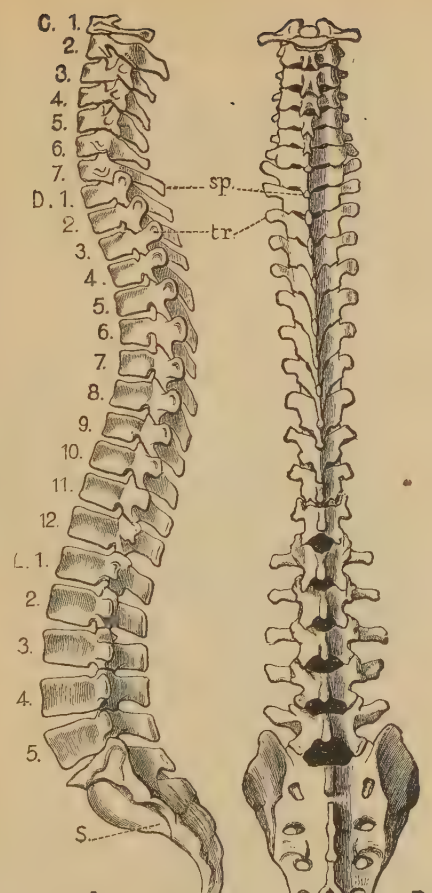


FIG. 2.—THE VERTEBRAL COLUMN.

A, side view, left side; B, back view; C 1-7, cervical vertebræ; D 1-12, rsal (thoracic) vertebræ; L 1-5, lumbar vertebræ; S, sacrum; C, ccyx; sp, spinous processes; tr, transverse processes.

the breast-bone or **sternum** (see Lesson IV.). In the girdle which supports the shoulder, two bones are always distinguishable as the **scapula** and the **clavicle**. The **pelvis**, to which the legs are attached, consists of two separate bones called the **ossa innominata** in the adult; but each os innominatum is separable into three (called **pubis, ischium**, and **ilium**) in the young.

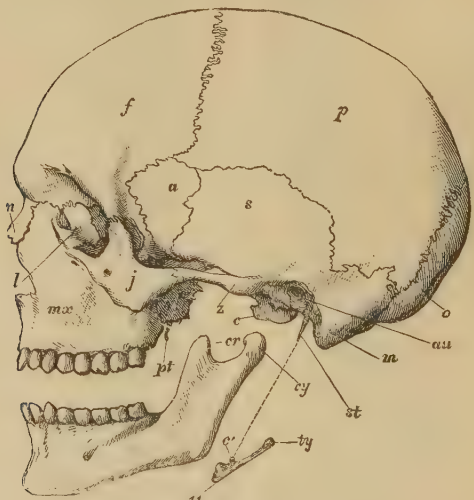


FIG. 3.—SIDE VIEW OF THE SKULL.

f, frontal bone; *p*, parietal; *o*, occipital; *a*, wing of sphenoid; *s*, flat part of temporal; *c*, *m*, *st*, other parts of temporal; *au*, opening of ear or external auditory canal; *z*, process of temporal passing to *j*, the cheek bone; *mx*, the upper jaw bone; *n*, nasal bone; *l*, lacrymal; *pt*, part of sphenoid. The lower jaw bone is drawn downwards; *cy*, its process which articulates with the temporal; *cr*, its process to which muscles of mastication are attached; *th*, *ty*, hyoid bone.

There are thirty bones in each of the arms, and the same number in each of the legs, counting the **patella**, or knee-pan.

All these bones are fastened together by ligaments, or by cartilages; and where they play freely over one another, a coat of cartilage furnishes the surfaces which come into contact. The cartilages which thus form part of a joint are called **articular** cartilages, and their free surfaces, by which they rub against each other, are lined by a delicate **synovial** membrane, which secretes a lubricating fluid—the **synovia**.

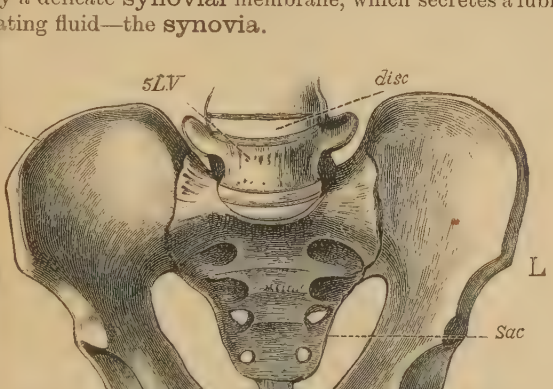


FIG. 4.—THE PELVIS.

Sac. sacrum; *Cocc.* coccyx; *il, is, pu*, ilium, ischium, pubis, three parts the innominate or hip bone; *acet*, acetabulum cup for head of femur; *L. V*, 5th lumbar vertebra.

5. The Erect Position.—Though the bones of the skeleton are all strongly enough connected together by ligaments and cartilages, the joints play so freely, and the centre of gravity of the body, when erect, is so high up, that it is impossible to make a skeleton or a dead body support itself in the upright position. That position, easy as it seems, is the result of the contraction of a multitude of muscles which

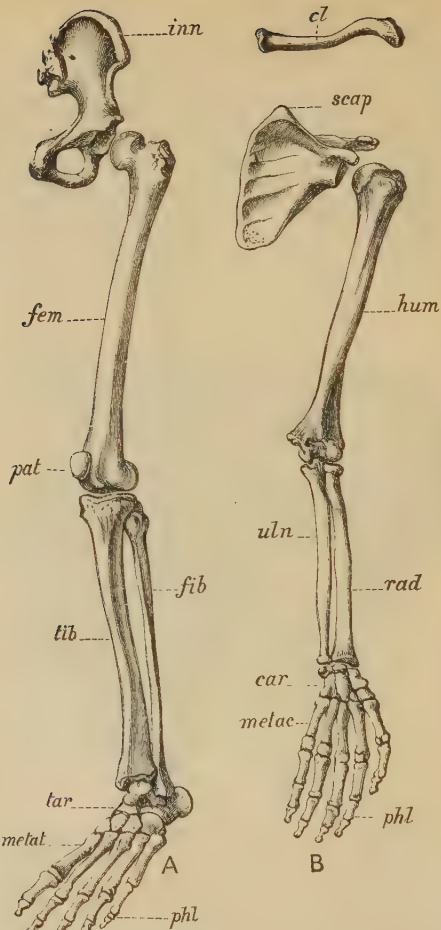


FIG. 5.—THE BONES OF THE LIMBS. FRONT VIEW. LEFT LIMBS.

A, the innominate and bones of the leg; *inn*, innominate; *fem*. femur; *pat*, patella or knee-cap; *tib*, tibia; *fib*, fibula; *tar*, (seven) tarsal bones; *metat*, (five) metatarsal bones; *phl*, (fourteen) phalanges; B, the scapula, clavicle, and bones of the arm; *cl*, clavicle or collar bone; *scap*, scapula or shoulder bone; *hum*, humerus; *rad*, radius; *uln*, ulna; *car*, (eight) carpal bones; *metac*, (five) metacarpal bones; *phl*, (fourteen) phalanges.

ppose and balance one another. Thus, the foot affording
e surface of support, the muscles of the calf (Fig. 6, I)

6.—A Diagram illustrating the Attachments of some of the most important Muscles which keep the Body in the Erect Posture.

The muscles of the calf. II. Those of the back of the thigh. III.
se of the spine. These tend to keep the body from falling forward.
The muscles of the front of the leg. 2. Those of the front of the
h. 3. Those of the front of the abdomen. 4, 5. Those of the front
he neck. These tend to keep the body from falling backwards. The
ws indicate the direction of action of the muscles, the foot being
d.

must contract, or the legs and body would fall forward. But this action tends to bend the leg ; and to neutralise this and keep the leg straight, the great muscles in front of the thigh (Fig. 6, 2) must come into play. But these, by the same action, tend to bend the body forward on the legs ; and if the body is to be kept straight, they must be neutralised by the action of the muscles of the buttocks and of the back (Fig. 6, III).

The erect position, then, which we assume so easily and without thinking about it, is the result of the combined and accurately proportioned action of a vast number of muscles. What is it that makes them work together in this way ?

Let any person in the erect position receive a violent blow on the head, and you know what occurs. On the instant he drops prostrate, in a heap, with his limbs relaxed and powerless. What has happened to him ? The blow may have been so inflicted as not to touch a single muscle of the body ; it may not cause the loss of a drop of blood ; and, indeed, if the "concussion," as it is called, has not been too severe, the sufferer, after a few moments of unconsciousness, will come to himself, and be as well as ever again. Clearly, therefore, no permanent injury has been done to any part of the body, least of all to the muscles, but an influence has been exerted upon a something which governs the muscles. And a similar influence may be the effect of very subtle causes. A strong mental emotion, and even a very bad smell, will, in some people, produce the same effect as a blow.

These observations might lead to the conclusion that it is the mind which directly governs the muscles, but a little further inquiry will show that such is not the case. For people have been so stabbed, or shot in the back, as to cut the spinal cord, without any considerable injury to other parts : and then they have lost the power of standing upright as much as before, though their minds may have remained perfectly clear. And not only have they

st the power of standing upright under these circumances, but they no longer retain any power of either feeling what is going on in their legs, or, by an act of their wn will, causing motion in them.

And yet, though the mind is thus cut off from the lower bs, a controlling and governing power over them still mains in the body. For if the soles of the disabled feet tickled, though the mind does not feel the tickling, e legs will be jerked up, just as would be the case in uninjured person. Again, if a series of galvanic shocks sent into the spinal cord, the legs will perform movents even more powerful than those which the will uld produce in an uninjured person. And, finally, if the jury is of such a nature as not simply to divide or injure e spinal cord in one place only, but to crush or profoundly disorganise it altogether, all these phenomena ase ; tickling the soles, or sending galvanic shocks along e spine, will produce no effect upon the legs.

By examinations of this kind carried still further, we rive at the remarkable result that while the brain is the at of all sensation and mental action, and the primary urce of all voluntary muscular contractions, the spinal rd is by itself capable of receiving an impression from e exterior, and converting it not only into a simple uscular contraction, but into a combination of such tions.

Thus, in general terms, we may say of the cerebro-inal nervous centres, that they have the power, when ey receive certain impressions from without, of giving se to simple or combined muscular contractions.

6. Sensory Organs.—But you will further note that ese impressions from without are of very different characters. Any part of the surface of the body may be so ffected as to give rise to the sensations of contact, or of eat or cold ; and any or every substance is able, under rtain circumstances, to produce these sensations. But nly very few and comparatively small portions of the

bodily framework are competent to be affected, in such a manner as to cause the sensations of taste or of smell, of sight or of hearing: and only a few substances, or particular kinds of vibrations, are able so to affect those regions. These very limited parts of the body, which put us in relation with particular kinds of substances, or forms of force, are what are termed **sensory organs.** There are two such organs for sight, two for hearing, two for smell, and one, or more strictly speaking two, for taste.

And now that we have taken this brief view of the structure of the body, of the organs which support it, of the organs which move it, and of the organs which put it in relation with the surrounding world, or, in other words, enable it to move in harmony with influences from without, we must consider the means by which all this wonderful apparatus is kept in working order.

All work, as we have seen, implies waste. The work of the nervous system and that of the muscles, therefore, implies consumption either of their own substance, or of something else. And as the organism can make nothing, it must possess the means of obtaining from without that which it wants, and of throwing off from itself that which it wastes; and we have seen that, in the gross, it does these things. The body feeds, and it excretes. But we must now pass from the broad fact to the mechanism by which the fact is brought about. The organs which convert food into nutriment are the organs of **alimentation**; those which distribute nutriment all over the body are organs of **circulation**; those which get rid of the waste products are organs of **excretion.**

7. **Alimentary Organs.** – The organs of alimentation are the mouth, pharynx, gullet, stomach, and intestines, with their appendages. What they do is, first to receive and grind the food. They then act upon it with chemical agents, of which they possess a store which is renewed as fast as it is used; and in this way convert the food by processes of digestion into a fluid containing nutritious

atters in solution or suspension, and innutritious dregs
fæces.

8. **Circulatory Organs.**—A system of minute tubes, th very thin walls, termed **capillaries**, is distributed rough the whole organism except the epidermis and its oducts, the epithelium, the cartilages, and the sub- nce of the teeth. On all sides, these tubes pass into ers, which are called **arteries** and **veins**; while ese, becoming larger and larger, at length open into the **eart**, an organ which, as we have seen, is placed in the orax. During life, these tubes and the chambers of e heart, with which they are connected, are all full of uid, which is, for the most part, that red fluid with hich we are all familiar as **blood.**

The walls of the heart are muscular, and contract ythmically, or at regular intervals. By means of these ntractions the blood which its cavities contain is driven jets out of these cavities, into the arteries, and thence to the capillaries, whence it returns by the veins back to the heart.

This is the **circulation of the blood.**

Now the fluid containing the dissolved or suspended utritive matters which are the result of the process of gestion, traverses the very thin layer of soft and per- able tissue which separates the cavity of the alimentary nal from the cavities of the innumerable capillary vessels ich lie in the walls of that canal, and so enters the ood, with which those capillaries are filled. Whirled way by the torrent of the circulation, the blood, thus harged with nutritive matter, enters the heart, and is ence propelled into the organs of the body. To these gans it supplies the nutriment with which it is charged; om them it takes their waste products, and, finally, turns by the veins to the heart, loaded with useless and injurious excretions, which sooner or later take the form water, carbonic acid, and urea.

9. **Excretory Organs.**—These excretionary matters

are separated from the blood by the **excretory organs**, of which there are three—the **skin**, the **lungs**, and the **kidneys**.

Different as these organs may be in appearance, they are constructed upon one and the same principle. Each, in ultimate analysis, consists of a very thin sheet of tissue, like so much delicate blotting-paper, the one face of which is free, or lines a cavity in communication with the exterior of the body, while the other is in contact with the blood which has to be purified.

The excreted matters are, as it were (though, as we shall see, in a peculiar way), strained from the blood, through this delicate layer of tissue, and on to its free surface, whence they make their escape.

Each of these organs is especially concerned in the elimination of one of the chief waste products—water, carbonic acid, and urea—though it may at the same time be a means of escape for the others. Thus the lungs are especially busied in getting rid of carbonic acid, but at the same time they give off a good deal of water. The duty of the kidneys is to excrete urea (together with other substances, chiefly salts), but at the same time they pass away a large quantity of water and a trifling amount of carbonic acid ; while the skin gives off much water, some amount of carbonic acid, and a certain quantity of saline matter, among which a trace of urea may be, sometimes, though very doubtfully, present.

10. **Respiratory Organs.**—Finally the lungs play a double part, being not merely eliminators of waste, or excretionary products, but importers into the economy of a substance which is not exactly either food or drink, but something as important as either,—to wit, **oxygen**.

As the carbonic acid (and water) is passing from the blood through the lungs into the external air, oxygen is passing from the air through the lungs into the blood, and is carried, as we shall see, by the blood to all parts of the body. We have seen (p. 6) that the waste which

aves the body contains more oxygen than the food which ters the body. Indeed oxidation, the oxygen being pplied by the blood, is going on all over the body. l parts of the body are thus continually being oxidised, , in other words, are continually burning, some more pidly and fiercely than others. And this burning, ough it is carried on in a peculiar manner, so as never give rise to a flame, yet nevertheless produces an ount of heat which is as efficient as a fire to raise the od to a temperature of about 37° C. (98° ·6 F.); and this t fluid, incessantly renewed in all parts of the economy the torrent of the circulation, warms the body, as a use is warmed by a hot-water apparatus. Nor is it one the heat of the body which is provided by this idation; the energy which appears in the muscular rk done by the body has the same source. Just as the rning of the coal in a steam-engine supplies the motive wer which drives the wheels, so, though in a peculiar y, the oxidation of the muscles (and thus ultimately of e food) supplies the motive power of those muscular ntractions which carry out the movements of the body. ne food, like coal combustible or capable of oxidation, built up into the living body, which in like manner mbustible, is continually being oxidised by the oxygen m the blood, thus doing work and giving out heat. me of the food perhaps may be oxidised without ever tually forming part of the body or after it has already ecome waste matter, but this does not concern us w.

11. Coordinating Action of the Nervous System.—hese alimentary, circulatory or distributive, excretory, d respiratory (oxidational) processes would however be orse than useless if they were not kept in strict propor- n one to another. If the state of physiological balance to be maintained, not only must the quantity of aliment ken be at least equivalent to the quantity of matter creted; but that aliment must be distributed with due

rapidity to the seat of each local waste. The circulatory system is the commissariat of the physiological army.

Again, if the body is to be maintained at a tolerably even temperature, while that of the air is constantly varying, the condition of the hot-water apparatus must be most carefully regulated.

In other words, a **coordinating organ** must be added to the organs already mentioned, and this is found in the **nervous system**, which not only possesses the function already described of enabling us to move our bodies and to know what is going on in the external world ; but makes us aware of the need of food, enables us to discriminate nutritious from innutritious matters, and to exert the muscular actions needful for seizing, killing, and cooking ; guides the hand to the mouth, governs all the movements of the jaws and of the alimentary canal, and determines the due supply of the juices necessary for digestion. By it, the working of the heart is properly adjusted and the calibres of the distributing pipes are regulated, so as indirectly to govern the excretory and oxidational processes, which are also additionally and more directly affected by other actions of the nervous system.

12. Life and Death.—The various functions which have been thus briefly indicated constitute the greater part of what are called the *vital actions* of the human body, and so long as they are performed, the body is said to possess *life*. The cessation of the performance of these functions is what is ordinarily called *death*.

But there are really several kinds of death, which may, in the first place, be distinguished from one another under the two heads of *local* and of *general* death.

(i) **Local death** is going on at every moment, and in most, if not in all, parts of the living body. Individual cells of the epidermis and of the epithelium are incessantly dying and being cast off, to be replaced by others which are, as constantly, coming into separate existence.

he like is true of blood-corpuscles, and probably of many her elements of the tissues.

This form of local death is insensible to ourselves, and essential to the due maintenance of life. But, occasionally, local death occurs on a larger scale, as the results of injury, or as the consequence of disease. A burn, for example, may suddenly kill more or less of the skin; part of the tissues of the skin may die, as in the case of the slough which lies in the midst of a boil; or a whole limb may die, and exhibit the strange phenomena of *mortification*.

The local death of some tissues is followed by their regeneration. Not only all the forms of epidermis and epithelium, but nerves, connective tissue, bone, and at a slow rate, some muscles, may be thus reproduced, even on a large scale.

(ii) **General death** is of two kinds, *death of the body as a whole*, and *death of the tissues*. By the former term is implied the absolute cessation of the functions of the brain, of the circulatory, and of the respiratory organs; by the latter, the entire disappearance of the vital actions of the ultimate structural constituents of the body. When death takes place, the body, as a whole, dies first, the death of the tissues not occurring until after an interval, which is sometimes considerable.

Hence it is that, for some little time after what is ordinarily called death, the muscles of an executed criminal may be made to contract by the application of proper stimuli. The muscles are not dead, though the man is.

13. **Modes of Death.**—The modes in which death is brought about appear at first sight to be extremely varied. We speak of natural death by old age, or by some of the endless forms of disease; of violent death by starvation, or by the innumerable varieties of injury, or poison. But, in reality, the immediate cause of death is always the stoppage of the functions of one of three organs;

the cerebro-spinal nervous system, the lungs, or the heart. Thus, a man may be instantly killed by such an injury to a part of the brain which is called the **spinal bulb** or **medulla oblongata** (see Lesson XI.) as may be produced by hanging, or breaking the neck.

Or death may be the immediate result of suffocation by strangulation, smothering, or drowning,—or, in other words, of stoppage of the respiratory functions.

Or, finally, death ensues at once when the heart ceases to propel blood. These three organs—the brain, the lungs, and the heart—have been fancifully termed the *tripod of life.*

In ultimate analysis, however, life has but two legs to stand upon, the lungs and the heart, for death through the brain is always the effect of the secondary action of the injury to that organ upon the lungs or the heart. The functions of the brain cease, when either respiration or circulation is at an end. But if circulation and respiration are kept up artificially, the brain may be removed without causing death. On the other hand, if the blood be not aërated, its circulation by the heart cannot preserve life ; and, if the circulation be at an end, mere aëration of the blood in the lungs is equally ineffectual for the prevention of death.

With the cessation of life, the everyday forces of the inorganic world no longer remain the servants of the bodily frame, as they were during life, but become its masters. Oxygen, the slave of the living organism, becomes the lord of the dead body. Atom by atom, the complex molecules of the tissues are taken to pieces and reduced to simpler and more oxidised substances, until the soft parts are dissipated chiefly in the form of carbonic acid, ammonia, water, and soluble salts, and the bones and teeth alone remain. But not even these dense and earthy structures are competent to offer a permanent resistance to water and air. Sooner or later the animal basis which holds together the earthy salts decomposes

nd dissolves—the solid structures become friable, and reak down into powder. Finally, they dissolve and are iffused among the waters of the surface of the globe, just s the gaseous products of decomposition are dissipated hrough its atmosphere.

It is impossible to follow, with any degree of certainty, anderings more varied and more extensive than those agined by the ancient sages who held the doctrine of ansmigration ; but the chances are, that sooner or later, me, if not all, of the scattered atoms will be gathered to new forms of life.

The sun's rays, acting through the vegetable world, uild up some of the wandering molecules of carbonic acid, t water, of ammonia, and of salts, into the fabric of lants. The plants are devoured by animals, animals evour one another, man devours both plants and other nimals ; and hence it is very possible that atoms which nce formed an integral part of the busy brain of Julius æsar may now enter into the composition of Cæsar the egro in Alabama, and of Cæsar the house-dog in an nglish homestead.

And thus there is sober truth in the words which hakespeare puts into the mouth of Hamlet—

> " Imperial Cæsar, dead and turned to clay,
> Might stop a hole to keep the wind away ;
> Oh that that earth, which kept the world in awe,
> Should patch a wall, to expel the winter's flaw ! "

LESSON II

THE ORGANS OF CIRCULATION

Part I.—The Blood Vascular System and the Circulation

1. The Capillaries.—Almost all parts of the body are *vascular*; that is to say, they are traversed by minute and very close-set canals, which open into one another so as to constitute a small-meshed network, and confer upon these parts a spongy texture. The canals, or rather tubes, are provided with distinct but very delicate walls, composed of what at first sight appears to be a structureless membrane,

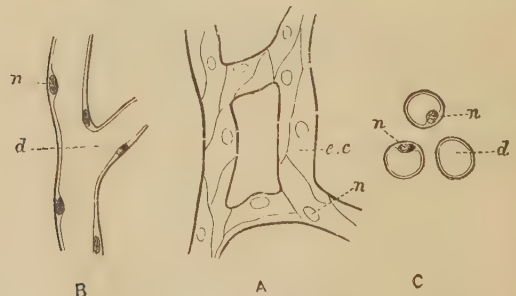


Fig. 7.—Capillaries.

A, surface view; B, cut lengthwise; C, cut across; *e c*, endothelial cells; *n*, nuclei; *d*, the lumen or bore.

ut is in reality formed of a number of thin scales, called cells," cemented together at their edges (Fig. 7, A, *e.c*); each of these cells lies a small oval body (Fig. 7, *n*), rmed a **nucleus.**

These tubes are the **blood capillaries.** They vary in ameter from 14 μ to 16 μ ($\frac{1}{2000}$ to $\frac{1}{1500}$ of an inch)[1]; y are sometimes disposed in loops, sometimes in long, metimes in wide, sometimes in narrow meshes; and the ameters of these meshes, or, in other words, the inter- aces between the capillaries, are sometimes hardly wider an the diameter of a capillary, sometimes many times as de (see Figs. 25, 39, 58, and 64). These interspaces are cupied by the substance of the tissue which the capillaries rmeate, so that the ultimate anatomical components of very part of the body are, strictly speaking, outside the ssels, or *extra-vascular.*

But there are certain parts of the body in which these lood-capillaries are absent. These are the epidermis d epithelium, the nails and hairs, the substance of the eth, and to a certain extent the cartilages and the trans- rent coat (cornea) of the eye in front; which may d do attain a very considerable thickness or length, and t contain no blood-vessels. However, since we have seen at all the tissues are really extra-vascular, these differ ly in degree from the rest. The circumstance that all e tissues are outside the vessels by no means interferes ith their being bathed by the fluid which is inside the ssels. In fact, the walls of the capillaries are so ex- edingly thin that their fluid contents readily exude rough the delicate membrane of which they are com- sed, and irrigate the tissues in which they lie.

2. **The Arteries and Veins.**—The capillary tubes so r described contain, during life, the red fluid, **blood,** nd are continued on opposite sides, into somewhat larger

[1] The ordinarily used unit of histological measurement is $\frac{1}{1000}$ of a illimeter, and is usually represented by the Greek letter μ, which ands for micro-millimeter. Since one millimeter is very nearly $\frac{1}{25}$ of n inch $\mu = \frac{1}{25000}$ of an inch.

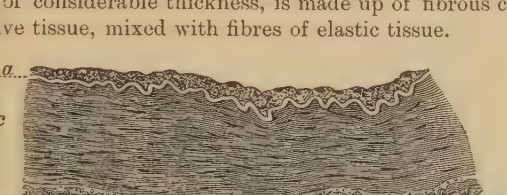
tubes, with thicker walls, which are the smallest **arteries**, on the one side and **veins** on the other, and these again join on to larger arteries and veins, which ultimately communicate by a few principal arterial and venous trunks with the heart.

The mere fact that the walls of these vessels are thicker than those of the capillaries constitutes an important difference between the capillaries and the small arteries and veins; for the walls of the latter are thus rendered far less permeable to fluids, and that thorough irrigation of the tissues, which is effected by the capillaries, cannot be performed by them.

The most important difference between these vessels and the capillaries, however, lies in the circumstance that their walls are not only thicker, but also more complex, being composed of several coats, one, at least, of which is muscular. The number, arrangement, and even nature of these coats differ according to the size of the vessels, and are not the same in the veins as in the arteries, though the smallest veins and arteries tend to resemble each other.

(i) **The Structure of an Artery.**—If we take one of the smallest arteries, we find, first, a very delicate lining of cells constituting a sort of epithelium continuous with the cells which form the entire thickness of the wall of the capillaries. Outside this comes the muscular coat, consisting of a thin layer of muscle-fibres of the kind called plain or non-striated (see Lesson VII.), made up of flattened spindle-shaped cells with an elongated nucleus, wrapped round the vessel at right angles to its length. Outside this muscular coat is a thin layer of fibrous connective tissue intermixed with a variable amount of fibres of elastic tissue (see Lesson XII.). The walls of the smallest arteries are thus seen to be made up essentially of three layers; the inner cellular, the middle muscular, the outer of connective tissue. The larger arteries are similarly composed of three layers or coats, which are, however, thicker and

re complex in structure. The inner coat now consists thin flattened cells lying on a distinct and special layer lastic tissue of variable thickness. The middle coat, which the thickness of the arterial wall is chiefly due, sists of alternating layers of plain muscle fibres, transversely to the axis of the vessel, and of elastic es which as a rule run lengthwise. The outer coat, of considerable thickness, is made up of fibrous con- ive tissue, mixed with fibres of elastic tissue.



8.—Transverse Section of part of the Wall of a medium-sized Artery, magnified 75 diameters. (Schäfer.)

epithelial (endothelial) layer of inner coat; *b*, elastic layer (fenes- d membrane) of inner coat, appearing in section as a bright line; scular layers (middle coat); *d*, outer coat, consisting of connective e bundles, interspersed with connective tissue nuclei, and, es- dly near the muscular coat, with elastic fibres cut across.

rom the above description of the structure of an artery see at once that arteries are **strong, muscular** and **stic.** The largest arteries are, as a rule, characteris- lly more elastic than the smaller, while in the latter muscular tissue is present in large amount *relatively* the elastic tissue. The significance of this difference become apparent later on (see pp. 62 and 65).

he plain muscular fibres in the arterial wall possess same power of contraction, or shortening in the long, broadening in the narrow, directions, which, as was ed in the preceding Lesson, is the special property of scular tissue. And when they exercise this power, they,

of course, narrow the calibre of the vessel, just as squeezing it with the hand or in any other way would do; and this contraction may go so far as, in some cases, to reduce the cavity of the vessel almost to nothing, and to render it practically impervious.

The state of contraction of these muscles of the small arteries is regulated, like that of other muscles, by their nerves; or, in other words, the nerves supplied to the vessels determine whether the passage through these tubes should be wide and free, or narrow and obstructed. Thus while the small arteries lose the function, which the capillaries possess, of directly irrigating the tissues by transudation, they gain that of **regulating the supply** of fluid to the irrigators or capillaries themselves. The contraction, or dilation, of the arteries which supply a set of capillaries, comes to the same result as lowering or raising the sluice-gates of a system of irrigation-canals. Thus the one great and all-important use of the muscular tissue of the smaller arteries is *to determine and control the supply of blood to each part of the body, according to the varying needs of that part.*

The smaller arteries and veins severally unite into, or are branches of, larger arterial or venous trunks, which again spring from or unite into still larger ones, and these, at length, communicate by a few principal arterial and venous trunks with the heart.

(ii) **The Structure of a Vein.**—The wall of a vein is structurally similar to that of an artery in so far that it consists essentially of the same three layers or coats, but the distinction between the middle and outer coats, so easily made out in an artery, is usually very obscure in a vein or even altogether wanting in some veins. It differs from that of an artery chiefly in the fact that it is thinner, less muscular and less elastic, and contains *relatively* more connective tissue. Hence the walls of a vein collapse or fall together when the vessel is empty, whereas those of an artery do not.

This is one great difference between the arteries and the ins; the other is the presence of what are termed **alves** in a great many of the veins, especially in those hich lie in muscular parts of the body. They are esent in the largest trunks such as the superior and erior vena cava, and in the smallest branches, as also the portal, pulmonary, and cerebral veins, and in those the bones.

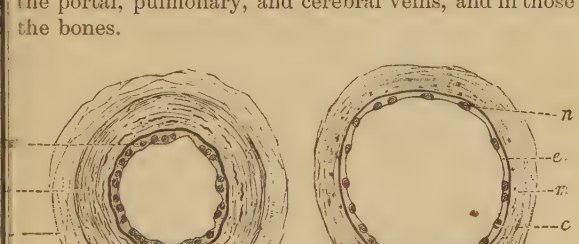


FIG. 9.—TRANSVERSE SECTION OF AN ARTERY AND OF A CORRESPONDING VEIN.

artery; V, vein; *ee*, endothelial cells; *m*, muscular (middle) coat; *c*, connective tissue (outer) coat; *n*, nuclei of endothelial cells.

These valves are pouch-like folds of the inner wall of vein. The bottom of the pouch is turned towards se capillaries from which the vein springs. The free ge of the pouch is directed the other way, or towards heart. The action of these pouches is to impede the ssage of any fluid from the heart towards the capillaries, ile they do not interfere with fluid passing in the oppoe direction (Fig. 10). The working of some of these ves may be very easily demonstrated in the living body. nen the arm is bared, blue veins may be seen running m the hand, under the skin, to the upper arm. The meter of these veins is pretty even, and diminishes

regularly towards the hand, so long as the current of the blood, which is running in them, from the hand to the upper arm, is uninterrupted.

But if a finger be pressed upon the upper part of one of these veins, and then passed downwards along it, so as to drive the blood which it contains backwards, sundry swellings, like little knots, will suddenly make their appearance at several points in the length of the vein, where nothing of the kind was visible before. These swellings are simply dilatations of the wall of the vein, caused by the pressure of the blood on that wall, above a valve which opposes its backward progress. The moment the backward impulse ceases the blood flows on again ; the

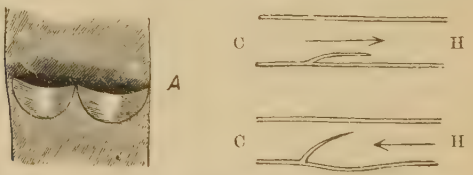


FIG. 10.—THE VALVES OF VEINS.

C, H, C, H, diagrammatic sections of veins with valves. In the upper figure the blood is supposed to be flowing in the direction of the arrow, towards the heart ; in the lower, back towards the capillaries ; C, capillary side ; H, heart side. A, a vein laid open to show a pair of pouch-shaped valves.

valve, swinging back towards the wall of the vein, affords no obstacle to its progress, and the distention caused by its pressure disappears (Fig. 10).

These valves play an important part in determining the flow of blood along the veins from the capillaries towards the heart. This they do *not* in virtue of any propulsive power of their own, *but in response to pressure applied to the veins from their exterior*. Such pressure tends to squeeze the blood out of that part of the vein on which it is brought to bear ; but since the valves only open towards the heart the blood is thereby driven on in the

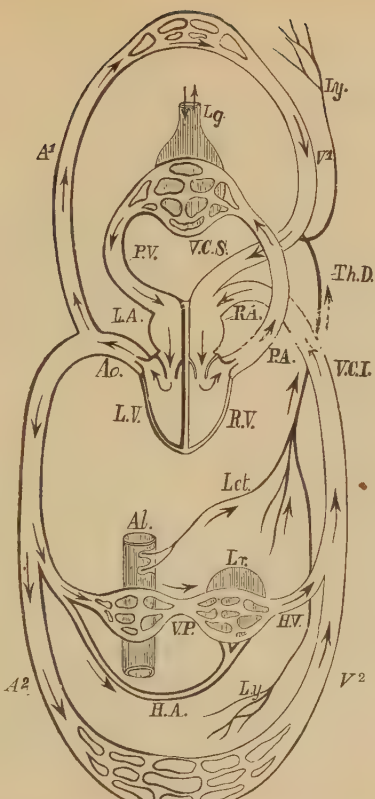


Fig. 11. Diagram of the Heart and Vessels, with the Course of the Circulation, viewed from behind, so that the proper left of the Observer corresponds with the left side of the Heart in the Diagram.

L.A. left auricle; *L.V.* left ventricle; *Ao.* aorta; A^1. arteries to the upper part of the body; A^2. arteries to the lower part of the body; *H.A.* hepatic artery, which supplies the liver with part of its blood; V^1. veins from the upper part of the body; V^2. veins of the lower part of the body; *V.P.* vena portæ; *H.V.* hepatic vein; *V.C.I.* inferior vena cava; *V.C.S.* superior vena cava; *R.A.* right auricle; *R.V.* right ventricle; *P.A.* pulmonary artery; *Lg.* lung; *P.V.* pulmonary vein; *Lct.* lacteals; *Ly.* lymphatics; *Th.D.* thoracic duct: *Al.* alimentary canal; *Lr.* liver. The arrows indicate the course of the blood, lymph, and chyle. The vessels which contain arterial blood have dark contours, while those which carry venous blood have light contours.

desired direction. Hence it is that the valves are most numerous in those veins which are most subject to muscular pressure, such as those of the arms and legs.

The only arteries which possess valves are the primary trunks—the aorta and pulmonary artery—which spring from the heart, but these valves, since they really belong to the heart, will be best considered with that organ.

3. The General Arrangement of Blood-vessels in the Body.—It will now be desirable to take a general view of the arrangement of all these different vessels, and of their relations to the great central organ of the vascular system—the heart (Fig. 11).

All the veins of every part of the body, except the lungs, the heart itself, and certain viscera of the abdomen, join together into larger veins, which, sooner or later, open into one of two great trunks (Fig. 11, *V.C.S. V.C.I.*) termed the **superior** and the **inferior vena cava**, which debouch into the upper or broad end of the right half of the heart.

All the arteries of every part of the body, except the lungs, are more or less remote branches of one great trunk—the **aorta** (Fig. 11, *Ao.*), which springs from the lower division of the left half of the heart.

The arteries of the lungs are branches of a great trunk, the **pulmonary artery** (Fig. 11, *P.A.*), springing from the lower division of the right side of the heart. The veins of the lungs, on the contrary, open by four trunks into the upper part of the left side of the heart (Fig. 11, *P.V.*), by the **pulmonary vein.**

Thus the venous trunks open into the upper division of each half of the heart: those of the body in general into that of the right half, those of the lungs into that of the left half; while the arterial trunks spring from the lower moieties of each half of the heart: that for the body in general from the left side, and that for the lungs from the right side.

Hence it follows that the great artery of the body, and

. 12.—Heart of Sheep, as seen after Removal from the Body, lying upon the two Lungs. The Pericardium has been cut away, but no other dissection made.

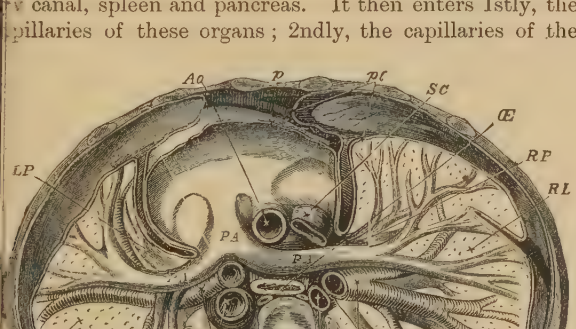
.A. auricular appendage of right auricle; *L.A.* auricular appendage left auricle; *R.V.* right ventricle; *L.V.* left ventricle; *S.V.C.* superior na cava; *I.V.C.* inferior vena cava; *P.A.* pulmonary artery; *Ao*, aorta; ', innominate branch from aorta dividing into subclavian and carotid eries; *L*, lung; *Tr.* trachea. 1, solid cord often present, the remnant a once open communication between the pulmonary artery and aorta. masses of fat at the bases of the ventricle hiding from view the greater t of the auricles. 3, line of fat marking the division between the o ventricles. 4, mass of fat covering end of trachea.

the great veins of the body, are connected with opposite sides of the heart; and the great artery of the lungs and the great veins of the lungs also with opposite sides of that organ. On the other hand, the veins of the body open into the same side of the heart as the artery of the lungs, and the veins of the lungs open into the same side of the heart as the artery of the body.

The arteries which open into the capillaries of the substance of the heart are called **coronary arteries**, and arise, like the other arteries, from the aorta, but quite close to its origin, just beyond the semilunar valves. But the **coronary vein**, which is formed by the union of the small veins which arise from the capillaries of the heart, does not open into either of the venæ cavæ, but pours the blood which it contains directly into the division of the heart into which these venæ cavæ open—that is to say, into the right upper division (Fig. 19, *b*).

The abdominal viscera referred to above, the veins of which do not take the usual course, are the stomach, the intestines, the spleen, and the pancreas. These veins all combine into a single trunk, which is termed the **portal vein** (Fig. 11, *V.P.*), but this trunk does not open into the inferior vena cava. On the contrary, having reached the liver, it enters the substance of that organ, and breaks up into an immense multitude of capillaries, which ramify through the liver, and become connected with those into which the artery of the liver, called the **hepatic artery** (Fig. 11, *H.A.*), branches. From this common capillary mesh-work veins arise, and unite, at length, into a single trunk, the **hepatic vein** (Fig. 11, *H.V.*), which emerges from the liver, and opens into the **inferior vena cava**. The flow of blood from the abdominal viscera through the liver to the hepatic vein is called the **portal circulation**. The portal vein is the only great vein in the body which branches out and becomes continuous with the capillaries of an organ, like an artery. But certain small veins in the kidney are similarly arranged. (Lesson V.)

The *shortest possible course* which any particle of the ood can take in order to pass from one side of the heart the other, is to leave the aorta by one of the coronary eries, and return to the right auricle by the coronary in. And in order to pass through the *greatest possible mber of capillaries* and return to the point from which started, a particle of blood must leave the heart by the ta and traverse the arteries which supply the aliment- canal, spleen and pancreas. It then enters 1stly, the pillaries of these organs ; 2ndly, the capillaries of the



G. 13.—Transverse Section of the Chest, with the Heart and Lungs in Place. (A little diagrammatic.)

D.V. dorsal vertebra, or joint of the backbone ; *Ao*, *Ao'*. aorta, the top its arch being cut away in this section ; *S.C.* superior vena cava ; *A.* pulmonary artery, divided into a branch for each lung ; *L.P. R.P.* ft and right pulmonary veins ; *Br.* bronchi ; *R.L. L.L.* right and left ngs ; *Œ.* the gullet or œsophagus ; *p.* outer bag of pericardium ; *pl.* the vo layers of pleura ; *v.* azygos vein.

ver ; and, 3rdly, after passing through the right side of he heart, the capillaries of the lungs, from which it eturns to the left side and eventually to the aorta.

4. **The Heart.**—The heart (Figs. 12 and 14), to which l the vessels in the body have now been directly or

indirectly traced, is an organ, the size of which is usually roughly estimated as equal to that of the closed fist of the person to whom it belongs, and which has a broad end turned upwards and backwards, and rather to the right side, called its **base** : and a pointed end which is called its **apex**, turned downwards and forwards, and to the left side, so as to lie opposite the interval between the fifth and sixth ribs.

It is lodged between the lungs, nearer the front than the back wall of the chest, and is enclosed in a sort of double bag—the **pericardium** (Fig. 13, *p.*). One-half of the double bag is closely adherent to the heart itself, forming a thin coat upon its outer surface. At the base of the heart, this half of the bag passes on to the great vessels which spring from, or open into, that organ ; and becomes continuous with the other half, which loosely envelopes both the heart and the adherent half of the bag. Between the two layers of the pericardium, consequently, there is a completely closed, narrow cavity, lined by an epithelium, and containing in its interior a small quantity of clear fluid, the **pericardial fluid.**[1]

The outer layer of the pericardium is firmly connected below with the upper surface of the diaphragm.

But the heart cannot be said to depend altogether upon the diaphragm for support, inasmuch as the great vessels which issue from or enter it—and for the most part pass upwards from its base—help to suspend and keep it in place.

Thus the heart is coated, outside, by one layer of the pericardium. Inside, it contains two great cavities or "divisions," as they have been termed above, completely separated by a fixed partition which extends from the base to the apex of the heart ; and consequently, having

[1] This fluid, like that contained in the peritoneum, pleura, and other shut sacs of a similar character to the pericardium, used to be called *serum* ; whence the membranes forming the walls of these sacs are frequently termed *serous membranes*. The fluid is, however, in reality a form of lymph. (See Lesson III.)

direct communication with one another. Each of se two great cavities is further subdivided, not gitudinally but transversely, by a movable partition. e cavity above the transverse partition on each side is ed the **auricle**; the cavity below, the **ventricle**—right left as the case may be.

Each of the four cavities has the same capacity, and is able of containing from 4 to 6 cubic inches of water

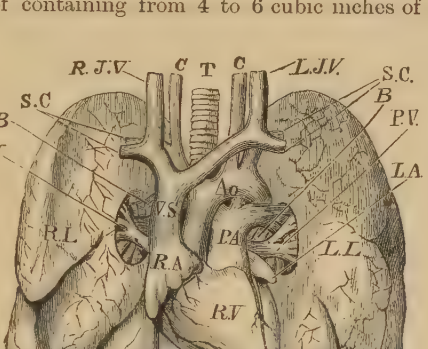


FIG. 14.—THE HEART, GREAT VESSELS, AND LUNGS. (FRONT VIEW.)

R.V. right ventricle; *L.V.* left ventricle; *R.A.* right auricle; *L.A.* left ricle; *Ao.* aorta; *P.A.* pulmonary artery; *P.V.* pulmonary veins; *R.L.* right lung; *L.L.* left lung; *V.S.* vena cava superior; *S.C.* subvian vessels; *C.* carotids; *R.J.V.* and *L.J.V.* right and left jugular ns; *V.I.* vena cava inferior; *T.* trachea; *B.* bronchi.

All the great vessels but those of the lungs are cut.

0 to 100 cubic centimeters). The walls of the auricles e much thinner than those of the ventricles. The wall the left ventricle is much thicker than that of the ght ventricle; but no such difference is perceptible tween the two auricles (Figs. 16 and 17, 1 and 3).

In fact, as we shall see, the ventricles have more work to do than the auricles, and the left ventricle more to do than the right. Hence the ventricles have more muscular substance than the auricles, and the left ventricle than the right ; and it is this excess of muscular substance which gives rise to the excess of thickness observed in the left ventricle.

The muscular fibres of the heart are of a peculiar nature, resembling those of the chief muscles of the body in being transversely striated, but differing from them in many other respects.

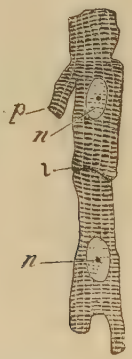


FIG. 15.—CARDIAC FIBRE CELLS.

Two cells isolated from the heart. *n*, nucleus ; *l*, line of junction between the two cells ; *p*, process joining a similar process of another cell. (Magnified 400 diameters.)

Cardiac Muscular Tissue.—The muscular tissue of the heart is intermediate in character between striated and non-striated muscle. Like the non-striated muscle, it is composed of cells, each containing a single nucleus, and possessing no sarcolemma. But the cells (Fig. 15) are generally short and broad, frequently branched or irregular in shape, and their substance is more or less distinctly

ated, like the substance of a striated fibre. A number such cells are joined by cement substance into sets of stomosing fibres, which are built up in a complex interen manner into the walls of the ventricles and auricles. The cavities of the heart are lined by a smooth, shiny brane called the **endocardium**, which consists of a er of connective tissue covered with thin flattened cells tinuous with and similar to those which form the wall the capillaries and which line the arteries and veins. the junction between the auricles and ventricles, apertures of communication between their cavities, ed the **auriculo-ventricular apertures**, are engthened by **fibrous rings** of connective tissue. To se rings the movable partitions, or valves, between auricles and ventricles, the arrangement of which st next be considered, are attached.

5. **The Valves of the Heart.**—There are three of se partitions attached to the circumference of the right riculo-ventricular aperture, and two to that of the left gs. 16, 17, 18, 19, *t v*, *m v*). Each is a broad, thin, but y tough and strong triangular fold of connective tissue e Lesson XII.) covered by endocardium, attached by base, which joins on to its fellow, to the auriculotricular fibrous ring, and hanging with its point nwards into the ventricular cavity. On the right there are, therefore, three of these broad, pointed mbranes, whence the whole apparatus is called the **cuspid valve**. On the left side, there are but two, ich, when detached from all their connexions but the iculo-ventricular ring, look something like a bishop's re, and hence bear the name of the **mitral lve.**

The edges and apices of the valves are not completely e and loose. On the contrary, a number of fine, but ng, tendinous cords, called **chordæ tendineæ**, con- t them with some column-like elevations of the fleshy stance of the walls of the ventricle, which are termed

papillary muscles (Figs. 16 and 17, *pp*); similar column-like elevations of the walls of the ventricles, but

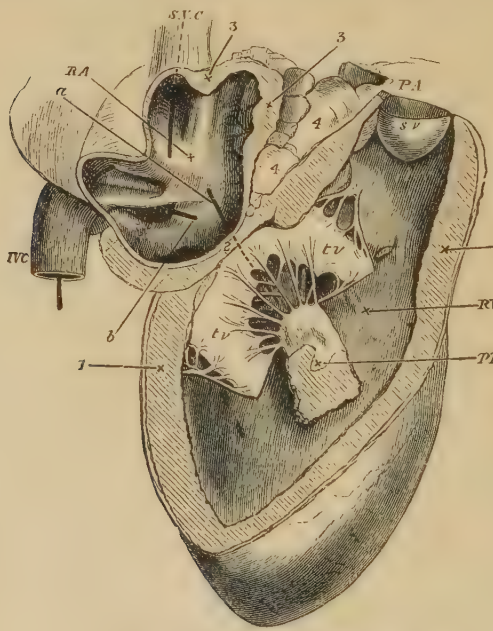


FIG. 16.—RIGHT SIDE OF THE HEART OF A SHEEP.

R.A. cavity of right auricle; *S.V.C.* superior vena cava; *I.V.C.* inferior vena cava; (a style has been passed through each of these;) *a*, a style passed from the auricle to the ventricle through the auriculo-ventricular orifice; *b*, a style passed into the coronary vein.

R.V. cavity of right ventricle; *tv*, *tv*, two flaps of the tricuspid valve; the third is dimly seen behind them, the style *a* passing between the three. Between the two flaps, and attached to them by *chordæ tendineæ*, is seen a papillary muscle, *pp*, cut away from its attachment to that portion of the wall of the ventricle which has been removed. Above, the ventricle terminates somewhat like a funnel in the pulmonary artery, *P.A.* One of the pockets of the semilunar valve *sv*, is seen in its entirety, another partially.

1, the wall of the ventricle cut across; 2, the position of the auriculo-ventricular ring; 3, the wall of the auricle; 4, masses of fat lodged between the auricle and pulmonary artery.

ving no chordæ tendineæ attached to them, are
led **columnæ carneæ**.

t follows, from this arrangement, that the valves
pose no obstacle to the passage of fluid from the
icles to the ventricles; but if any should be forced
other way, it will at once get between the valve and
wall of the heart, and drive the valve backwards and
wards. Partly because they soon meet in the middle
l oppose one another's action, and partly because the
rdæ tendineæ hold their edges and prevent them from
ng back too far, the valves, thus forced back, give rise
the formation of a complete transverse partition be-
en the ventricle and the auricle, through which no
id can pass.

Where the aorta opens into the left ventricle, and
ere the pulmonary artery opens into the right ventricle
other valvular apparatus is placed, consisting in each
e of three pouch-like valves called the **semilunar**
lves (Fig. 16, *s.v.* ; Figs. 18 and 19, *Ao. P.A.*), which
similar to those of the veins. Since they are placed on
same level and meet in the middle line, they completely
p the passage when any fluid is forced along the artery
wards the heart. On the other hand, these valves flap
k and allow any fluid to pass from the heart into the
ery, with the utmost readiness.

The action of the auriculo-ventricular valves may be
monstrated with great ease on a sheep's heart, in which
e aorta and pulmonary artery have been tied and the
eater part of the auricles cut away, by pouring water
o the ventricles through the auriculo-ventricular aper-
re. The tricuspid and mitral valves then usually
come closed by the upward pressure of the water which
ts behind them. Or, if the ventricles be nearly filled,
e valves may be made to come together at once by
ntly squeezing the ventricles. In like manner, if the
se of the aorta, or pulmonary artery, be cut out of the
art, so as not to injure the semilunar valves, water

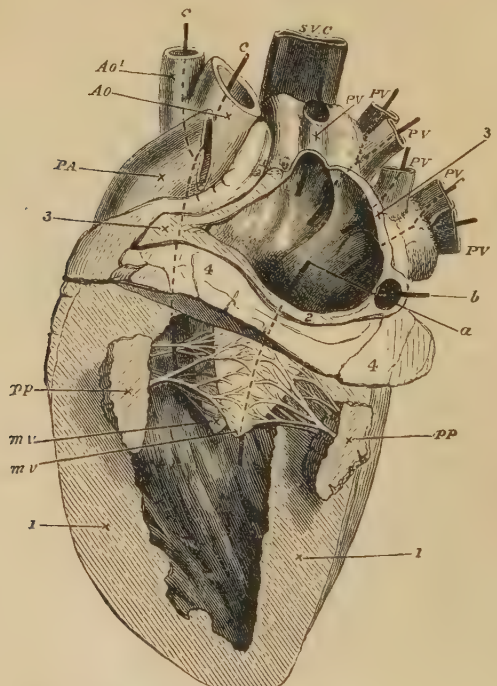


FIG. 17.—LEFT SIDE OF THE HEART OF A SHEEP (LAID OPEN).

P.V. pulmonary veins opening into the left auricle by four openings, as shown by the styles; *a*, a style passed from auricle into ventricle through the auriculo-ventricular orifice; *b*, a style passed into the coronary vein, which, though it has no connexion with the left auricle, is, from its position, necessarily cut across in thus laying open the auricle.

M.V. the two flaps of the mitral valve (drawn somewhat diagrammatically); *p.p*, papillary muscles, belonging as before to the part of the ventricle cut away; *c*, a style passed from ventricle in *Ao.* aorta; *Ao*¹. branch of aorta (see Fig. 12, *A'o'*); *P.A.* pulmonary artery; *S.V.C.* superior vena cava.

1, wall of ventricle cut across; 2, wall of auricle cut away around auriculo-ventricular orifice; 3, other portions of auricular wall cut across; 4, mass of fat around base of ventricle (see Fig. 12, 2).

oured into the upper ends of the vessel will cause its alves to close tightly, and allow nothing to flow out after ne first moment.

Thus the arrangement of the auriculo-ventricular valves such, that any fluid contained in the chambers of the eart can be made to pass through the auriculo-ventricular ertures in one direction only: that is to say, from the uricles to the ventricles. On the other hand, the arrangeent of the semilunar valves is such that the fluid con-

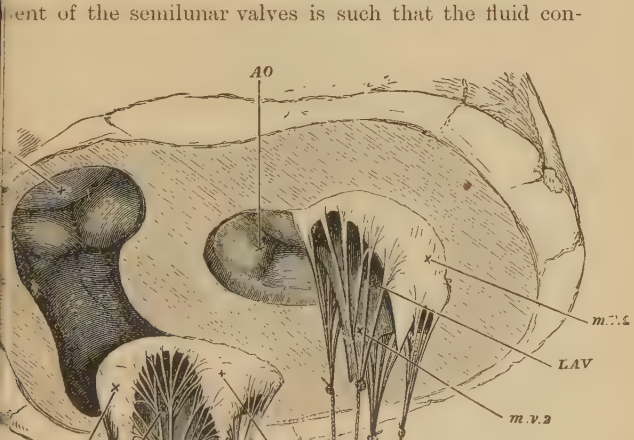


FIG. 18.—VIEW OF THE ORIFICES OF THE HEART FROM BELOW, THE WHOLE OF THE VENTRICLES HAVING BEEN CUT AWAY.

R.A.V. right auriculo-ventricular orifice surrounded by the three flaps, *t.v.* 1, *t.v.* 2, *t.v.* 3, of the tricuspid valve; these are stretched by weights attached to the *chordæ tendineæ*.

L.A.V. left auriculo-ventricular orifice surrounded in same way by the two flaps, *m.v.* 1, *m.v.* 2, of mitral valve; *P.A.* the orifice of pulmonary artery, the semilunar valves having met and closed together; *Ao.* the orifice of the aorta with its semilunar valves. The shaded portion, leading from *R.A.V.* to *P.A.*, represents the funnel seen in Fig. 16.

tents of the ventricles pass easily into the aorta and pulmonary artery, while none can be made to travel the other way from the arterial trunks to the ventricles.

6. The Beat of the Heart.—Like all other muscular tissues, the substance of the heart is contractile ; but, unlike most muscles, the heart contains within itself a some-

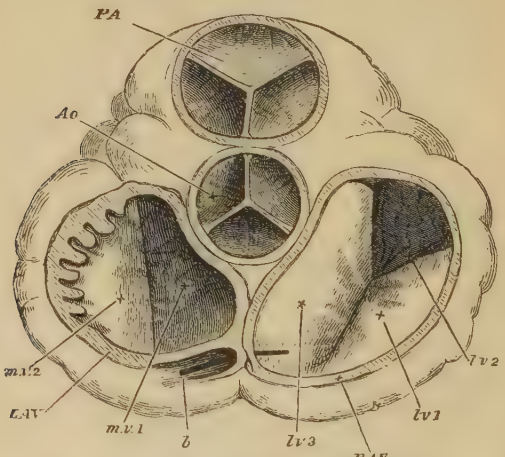


FIG. 19.—THE ORIFICES OF THE HEART SEEN FROM ABOVE THE AURICLES AND GREAT VESSELS BEING CUT AWAY

P.A. pulmonary artery, with its semilunar valves ; *Ao.* aorta do.

R.A.V. right auriculo-ventricular orifice with the three flaps (*l.v.* 1, 2, 3) of tricuspid valve.

L.A.V. left auriculo-ventricular orifice, with *m.v.* 1 and 2, flaps of mitral valve ; *b*, style passed into coronary vein. On the left part of *L.A.V.*, the section of the auricle is carried through the auricular appendage ; hence the toothed appearance due to the portions in relief cut across.

thing which causes its different parts to contract in a definite succession and at regular intervals.

If the heart of a living animal be removed from the body, it will, though in most cases for a very short time only,

unless the animal be "cold-blooded" like a frog, go on beating much as it did while in the body. And careful attention to these beats will show that they consist of :— (1) A simultaneous contraction of the walls of both auricles. (2) Immediately following this, a simultaneous contraction of the walls of both ventricles. (3) Then comes a pause, or state of rest ; after which the auricles and ventricles contract again in the same order as before, and their contractions are followed by the same pause as before.

The state of contraction of the ventricle or auricle is called its *systole* ; the state of relaxation, during which it undergoes dilation, its *diastole*.

If the auricular contraction be represented by A˘, the ventricular by V˘, and the pauses by —, the series of actions will be as follows : A˘ V˘ — ; A˘ V˘ — ; A˘ V˘ — ; &c. Thus, the contraction of the heart is **rhythmical**, two short contractions of its upper and lower halves respectively being followed by a pause of the whole, which occupies nearly as much time as the two contractions.

The movements taking place in the heart during one complete beat and the pause are usually spoken of as a "cardiac cycle." This cycle is repeated, or as we more ordinarily say, "the heart beats" in an average healthy adult person about 72 times in a minute. From this it follows that the ordinary duration of each beat is $\frac{8}{10}$ of a second. Of this period the contraction of the auricles occupies $\frac{1}{10}$ and that of the ventricles $\frac{3}{10}$, the remaining $\frac{4}{10}$ being taken up by the pause of the heart as a whole. During each cycle or beat the heart undergoes certain changes of shape and position, as to the details of which there is some uncertainty, but which are, on the whole, as follows. During each systole the width of the heart from side to side becomes less ; probably also the depth from back to front is at the same time slightly increased. The result of this is that whereas

during diastole the shape of a section of the base of the ventricles is elliptical, during systole it becomes much more nearly circular.

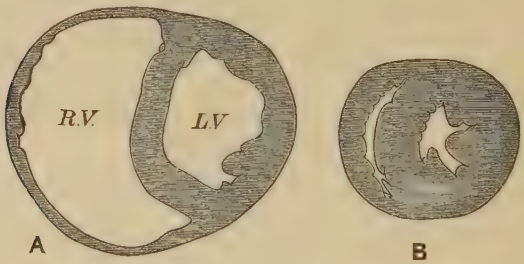


FIG. 20.--TRANSVERSE SECTION THROUGH THE MIDDLE OF THE VENTRICLES OF A DOG'S HEART IN DIASTOLE AND IN SYSTOLE. (AFTER HESSE.)

R.V. right ventricle; *L.V.* left ventricle.

The length of the heart is very slightly lessened, if at all, during systole, but the heart as a whole is twisted to a certain extent on its long axis, from the left and behind towards the front and right. The apex is at the same time tilted slightly forward and is hence pressed rather more firmly against the wall of the thorax, a fact of some importance in connection with what we shall describe presently as the "cardiac impulse" (see p. 57).

7. The Action of the Valves.—Having now acquired a notion of the arrangement of the different pipes and reservoirs of the circulatory system, of the position of the valves, and of the rhythmical contractions of the heart, it will be easy to comprehend what must happen if, when the whole apparatus is full of blood, the first step in the pulsation of the heart occurs and the auricles contract.

By this action each auricle tends to squeeze the fluid which it contains out of itself in two directions—the one towards the great veins, the other towards the ventricles; and the direction which the blood, as a whole, will take,

will depend upon the relative resistance offered to it in these two directions. Towards the great veins it is assisted by the mass of the blood contained in the veins. Towards the ventricles, on the contrary, there is no resistance worth mentioning, inasmuch as the valves are open, the walls of the ventricles, in their uncontracted state, are flaccid and easily distended, and the entire pressure of the arterial blood is taken off by the semilunar valves, which are necessarily closed. The return of blood into the veins is further checked by a contraction of the great veins at their point of junction with the heart which immediately precedes the systole of the auricles, and is practically continuous with it.

Therefore, when the auricles contract, little or none of the fluid which they contain will flow back into the veins; all the contents or nearly so will pass into and distend the ventricles. As the ventricles fill and begin to resist further distension, the blood, getting behind the auriculo-ventricular valves, will push them towards one another, and indeed almost shut them. The auricles now cease to contract, and immediately that their walls relax, fresh blood flows from the great veins and slowly distends them again.

But the moment the auricular systole is over, the ventricular systole begins. The walls of each ventricle contract vigorously, and the first effect of that contraction is to complete the closure of the auriculo-ventricular valves and so to stop all egress towards the auricle. The pressure upon the valves becomes very considerable, and they might even be driven upwards, if it were not for the *chordæ tendineæ* which hold down their edges.

As the contraction continues and the capacities of the ventricles become diminished, the points of the wall of the heart to which the *chordæ tendineæ* are attached approach the edges of the valves; and thus there is a tendency to allow of a slackening of these cords, which, if it really took place, might permit the edges of the valves

to flap back and so destroy their utility. This tendency, however, is counteracted by the *chordæ tendineæ* being connected, not directly to the walls of the heart, but to those muscular pillars, the *papillary muscles*, which stand out from its substance. These muscular pillars shorten at the same time as the substance of the heart contracts; and thus, just so far as the contraction of the walls of the ventricles brings the *papillary muscles* nearer the valves, do they, by their own contraction, pull the *chordæ tendineæ* as tight as before.

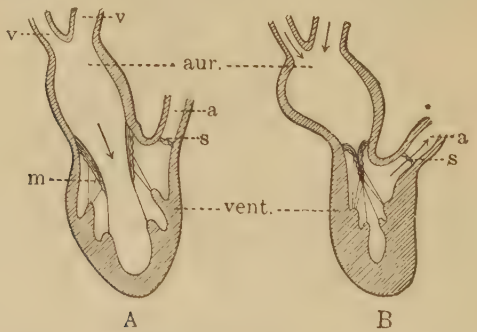


FIG. 21.—DIAGRAM TO ILLUSTRATE THE ACTION OF THE HEART.

aur. auricle; *vent.* ventricle; VV. veins; *a*, aorta; *m*, mitral valve; *s*, semilunar valve.

In A the auricle is contracting, ventricle dilated, mitral valve open, semilunar valves closed. In B the auricle is dilated, ventricle contracting, mitral valve closed, semilunar valves open.

By the means which have now been described, the fluid in the ventricle is debarred from passing back into the auricle; the whole force of the contraction of the ventricular walls therefore is expended in overcoming the resistance presented by the semilunar valves. This resistance is partly the result of the mere weight of the vertical column of blood which the valves support; but is chiefly due to the reaction of the distended elastic walls of the

reat arteries, for as we shall see, these arteries are already
full that the blood within them is pressing on their
alls with great force.

It now becomes obvious why the ventricles have so
uch more to do than the auricles, and why valves are
ded between the auricles and ventricles, while none
e wanted between the auricles and the veins.

All that the auricles have to do is to fill the ventricles,
hich offer no active resistance to that process. Hence
e thinness of the walls of the auricles, and hence the
edlessness of any auriculo-venous valve, the resistance
the side of the ventricle being so insignificant that it
ves way, at once, before the pressure of the blood in the
ins.

On the other hand, the ventricles have to overcome a
reat resistance in order to force fluid into elastic tubes
hich are already full; and if there were no auriculo-
ntricular valves, the fluid in the ventricles would meet
ith less obstacle in pushing its way backward into the
ricles and thence into the veins, than in separating the
milunar valves. Hence the necessity, firstly, of the
riculo-ventricular valves; and, secondly, of the thick-
ss and strength of the walls of the ventricles. And
nce the aorta, systemic arteries, capillaries, and veins
rm a system of tubes, which, from a variety of causes,
fer more resistance than do the pulmonary arteries,
pillaries, and veins, it follows that the left ventricle
eeds a thicker muscular wall than the right.

Thus, at every systole of the auricles, the ventricles
e filled and the auricles emptied, the latter being slowly
filled by the pressure of the fluid in the great veins,
hich is amply sufficient to overcome the passive resist-
nce of the relaxed auricular walls. And, at every systole
f the ventricles, the arterial systems of the body and
ngs receive the contents of these ventricles, and the
mptied ventricles remain ready to be filled by the
uricles.

8. The Working of the Arteries.—We must now consider what happens in the arteries when the contents of the ventricles are suddenly forced into these tubes (which, it must be recollected, are already full).

If the vessels were tubes of a rigid material, like gas-pipes, the forcible discharge of the contents of the left ventricle into the beginning of the aorta would send a shock, travelling with great rapidity, right along the whole system of tubes, through the arteries into the capillaries, through the capillaries into the veins, and through these into the right auricle; and just as much blood would be driven from the end of the veins into the right auricle as had escaped from the left ventricle into the beginning of the aorta; and that, at almost the same instant of time. And the same would take place in the pulmonary vessels between the right ventricle and left auricle.

However, the vessels are not rigid, but, on the contrary, very yielding tubes; and the great arteries, as we have seen, have especially elastic walls. On the other hand, the *friction* in the small arteries and capillaries which opposes a resistance to the flow of blood, and is hence spoken of as the **peripheral resistance**, is so great that the blood cannot pass through them into the veins as quickly as it escapes from the ventricle into the aorta. Hence the contents of the ventricle, driven by the force of the systole past the semilunar valves, are at first lodged in the first part of the aorta, the walls of which are stretched and distended by the extra quantity of blood thus driven into it. But as soon as the ventricle has emptied itself and no more blood is driven out of it to stretch the aorta, the elastic walls of this vessel come into play; they strive to go back again and make the tube as narrow as it was before; thus they return back to the blood the pressure which they received from the ventricle. The effect of this elastic recoil of the arterial walls is on the one hand to

se the semilunar valves, and so prevent the return of
d to the heart, and, on the other hand, to distend the
t portion of the aorta, driving an extra quantity of
d into it. And this second portion, in a similar
, distends the next, and this again the next, and so
right through the whole arterial system. Thus the
ulse given by the ventricle travels like a wave along
arteries, distending them as it goes, and ultimately
ing the blood through the capillaries into the veins,
l so on to the heart again.

Several of the practical results of the working of the
rt and arteries just described now become intelligible.

8. **The Cardiac Impulse.**—If a finger be placed on the
st over the space between the fifth and sixth ribs on
left side, about one inch below the left nipple and
htly towards the sternum, a certain throbbing move-
nt is perceptible, which is known as the "cardiac
pulse." It is the result of the heart-beat making it-
f felt through the wall of the chest at this point, at the
ment of the systole of the ventricles. Even when the
rt is at rest the apex, in a standing position, lies close
er and in contact with this part of the chest-wall.
hen the systole takes place the muscular substance of
ventricles becomes suddenly hard and tense, as do all
scles when they contract. At the same time the apex of
heart, as the result of the peculiar movements already
cribed (p. 52), is brought into still firmer contact with
chest-wall. The cardiac impulse is the outcome of this
lden hardening of the ventricular walls, aided by their
ser contact with the wall of the chest at the moment
en the hardening takes place. It is *not* due, as is so
quently stated, to the heart "striking" or "tapping"
inst the chest-wall.

10. **The Sounds of the Heart.**—If the ear be applied
r the heart, certain *sounds* are heard, which recur with
at regularity, at intervals corresponding with those
ween every two beats. First comes a longish dull

booming sound ; then a short sharp sound, then a pause, then the long, then the sharp sound, then another pause ; and so on. These sounds are usually likened to the pronunciation of the syllables "lŭbb," "dŭp." There are many different opinions as to the cause of the first sound ; some physiologists regard it as a muscular sound caused by the contraction of the muscular fibres of the ventricle, while others believe it to be due to the vibration of the auriculo-ventricular valves, when they become suddenly tense or stretched as the ventricles begin to contract. In reality the first sound has probably a double origin, being partly muscular and partly valvular, and this view is borne out by the following facts. The sound is given out during the ventricular systole and is most plainly heard at the spot where the cardiac impulse is most readily felt. It is greatly altered in character and obscured in cases of disease, or experimental injury of the auriculo-ventricular valves ; but on the other hand it may be heard, although modified, in a beating heart through whose cavities the passage of blood is temporarily prevented.

The second sound is without doubt caused by the membranes of the semilunar valves becoming tense, and thus thrown into vibrations, on their sudden closure at the end of the ventricular systole. This is proved by the facts that the sound is loudest at that point on the chest-wall under which the semilunar valves lie ; that it is modified and obscured by disease of these valves ; and that it may be made to cease by experimentally hooking back the semilunar valves in a living animal.

11. Blood-pressure. When an artery is cut, the outflow of blood is not uniform and smooth, but takes place in *jerks* which correspond to each beat of the heart. Moreover the blood *spurts out with considerable force*, which although it is greater at each jerk is still persistent and large between the jerks. The obvious conclusion to be drawn from the above observation is that the blood in

rtery is always under considerable, though variable, ure. This pressure is called **blood-pressure.** We already explained how this pressure comes to be lished ; but its importance is so great as a factor in irculation that we may with advantage refer to this once more.

e smallest arteries and capillaries offer a considerable nal resistance to the flow of blood through them he veins, called as we have already said, "peripheral tance." Owing to this resistance, of the total amount ood forced into the arteries at each beat of the heart, a portion can during the actual beat, apart from the e between it and the next beat, pass on into the s. The remainder is lodged in the arteries whose , being distensible, are *put on the stretch by the ure of the blood thrust into them at each stroke of the t*, and this pressure of the blood on the arterial wall hat we mean by "blood-pressure." As soon as the rial walls are stretched their *elastic* properties come into ; they *recoil* and press on the blood with a force l to that which puts them on the stretch. This ic recoil squeezes the blood on in the intervals een the successive beats of the heart, and thus ers the circulation continuous. In short the whole rial system is always in a state of distension ; the of the heart consists in keeping up this distended ition by thrusting fresh blood into the arteries under ssure ; and the pressure thus established forces the d through the capillaries, on through the veins, and ack to the heart.

lood-pressure is greatest in the large arteries near the t and diminishes *gradually* along the arterial system l we come to the smallest arteries and capillaries ; the pressure falls *suddenly*. The sudden fall of ssure is due to the existence of what we have already rred to as "peripheral resistance." This resistance t be overcome in order to drive the blood on into the

veins; to overcome a resistance work must be done, and to do work, force must be employed and energy expended. Now blood-pressure is the force available for overcoming the resistance, and if it be thus used up there is less of it left, or in other words the pressure falls. In the veins the blood-pressure is still less than in the capillaries, and diminishes gradually along their course towards the heart.

These differences of pressure in the several parts of the vascular system determine the flow of blood along the vessels; the blood is always flowing from a higher to a lower pressure; the main work of the heart is to establish the large blood-pressure existing in the larger arteries.

When a vein is cut the blood does not spurt out as it does from a cut artery but oozes or trickles out gently, the reason being that the pressure in the veins is small. Further the flow is in this case continuous and not jerky as it is from a cut artery, in correspondence with the fact that there is no "pulse" in the veins as there is in the arteries. But this statement requires that we should next consider the nature and causes of the pulse.

12. **The Pulse.**—If the finger be placed on an artery which lies near the surface of the body, such as the *radial artery* at the wrist, what is known as the pulse will be felt as a slight throbbing pressure on the finger, coming and going at regular intervals which correspond to the successive beats of the heart. What is felt is in reality the intermittent rise and fall of that piece of the arterial wall which lies immediately under the finger. This fact may be easily proved by placing a light lever so as to rest over the artery, whereupon its end may be *seen* to rise and fall at the same regular intervals. This movement of the arterial wall is due to that distension of the arteries of which we have already spoken, which is started at each beat of the heart by the extra quantity of blood driven into them by the ventricle, then travels in the form of a wave from the larger to the smaller arteries, and corre

ds to the jerky outflow of blood from a cut
y.

e pulse which is felt by the finger does not correspond
me precisely with the beat of the heart, but takes
a little after it, and the delay is longer, the greater
istance of the artery from the heart. For example,
pulse in the *tibial artery* on the inner side of the
is a little later than the pulse in the *temporal artery*
e temple. By suitable instruments the rate at which
ulse travels along the arteries may be readily deter-
d and is found to be about 30 feet per second. This
of progression of the pulse-wave must be carefully
nguished from the rate at which the blood is flowing
in the artery. Even in the aorta, where the blood
most rapidly (p. 64), the velocity is not more than
t 15 inches per second. In fact "the pulse-wave
ls over the moving blood somewhat as a rapidly
ng natural wave travels along a sluggishly flowing
."

der ordinary circumstances, the pulse is no longer to
etected in the capillaries, or in the veins. Sometimes
kward pulse from the heart along the great venous
ks may be observed ; but this is quite another matter,
is the result of the movements of breathing. (See
on IV.) This actual loss, or rather transformation of
pulse, is effected *by means of the elasticity of the arterial
, called into play by the peripheral resistance*, in the
wing manner.

the first place it must be borne in mind that, owing
ne minute size of the small arteries and capillaries, the
unt of friction taking place in their channels when the
d is passing through them is very great ; in other
ls, they offer a very great resistance to the passage of
blood. The consequence of this is, that, in spite of
fact that the total area of the capillaries is so much
ter than that of the aorta, the blood has a difficulty in
ing through the capillaries into the veins as fast as it

is thrown into the arteries by the heart. The whole arterial system, therefore, becomes over-distended with blood.

Now we know by experiment that under such conditions as these, an elastic tube has the power, if long enough and elastic enough, to change a jerked impulse into a continuous flow.

If an ordinary syringe or other convenient form of pump be fastened to one end of a long glass tube, and water be forced through the tube, it will flow from the far end in jerks, corresponding to the jerks of the syringe. This will be the case whether the tube be quite open at the far end, or drawn out to a fine point so as to offer great resistance to the outflow of the water. The glass tube is a rigid tube, and there is no elasticity to be brought into play.

If now a long india-rubber tube be substituted for the glass tube, it will be found to act differently, according as the opening at the far end is wide or narrow. If it is wide, the water flows out in jerks, nearly as distinct as those from the glass tube. There is little resistance to the outflow, little distension of the india-rubber tube, little elasticity brought into play. If, however, the opening be narrowed, as by fastening to it a glass tube drawn out to a fine point, or if a piece of sponge be thrust into the end of the tube—if, in fact, in any way resistance be offered to the outflow of the water, the tube becomes distended, its elasticity is brought into play, and the water flows out from the end, not in jerks but in a stream, which is more and more completely continuous the longer and more elastic the tube, and the greater the resistance at its open end.

Substitute for the syringe the heart, for the fine drawn glass tube or sponge the small arteries and capillaries, for the india-rubber tube the whole arterial system, and you have exactly the same result in the living body. Through the action of the elastic arterial walls the separate

from the heart are blended into one continuous
m. The whole force of each blow of the heart is not
ce spent in driving a quantity of blood through the
laries ; a part only is thus spent, the rest goes to
nd the elastic arteries. But during the interval
een that beat and the next the distended arteries are
wing again, by virtue of their elasticity, and so are
ing the blood on into the capillaries with as much
as they were themselves distended by the heart.
comes another beat, and the same process is re-
d. At each stroke the elastic arteries shelter the
aries from part of the sudden blow, and then quietly
teadily pass on that part of the blow to the capillaries
ng the interval between the strokes.

e larger the amount of elastic arterial wall thus
ght into play, *i.e.* the greater the distance from the
t, the greater is the fraction of each heart's stroke
h is thus converted into a steady elastic pressure
een the beats. Thus the pulse becomes less and
narked the farther you go from the heart ; any given
h of the arterial system, so to speak, being sheltered
e lengths between it and the heart.

ery inch of the arterial system may, in fact, be con-
ed as converting a small fraction of the heart's jerk
a steady pressure, and when all these fractions are
ned up together in the total length of the arterial
m no trace of the jerk is left.

the immediate, sudden effect of each systole becomes
nished in the smaller vessels by the causes above
ioned, the influence of this constant pressure becomes
obvious, and gives rise to a steady passage of the
from the arteries towards the veins. In this way, in
the arteries perform the same functions as the air-
voir of a fire-engine, which converts the jerking
lse given by the pumps into the steady flow from
nozzle of the delivery hose.

e phenomena so far described are the direct outcome

of the mechanical conditions of the organs of the circulation combined with the rhythmical activity of the heart. This activity drives the fluid contained in these organs out of the heart into the arteries, thence to the capillaries, and from them through the veins back to the heart. And in the course of these operations it gives rise, incidentally, to the cardiac impulse, the sounds of the heart, blood-pressure, and the pulse.

13. The Rate of Blood Flow.—It has been found, by experiment, that in the horse it takes about half a minute for any substance, as for instance a chemical body, whose presence in the blood can easily be recognized, to complete the circuit, *ex. gr.* to pass from the jugular vein down through the right side of the heart, the lungs, the left side of the heart, up through the arteries of the head and neck, and so back to the jugular vein.

By far the greater portion of this half minute is taken up by the passage through the capillaries, where the blood moves, it is estimated, at the rate only of about one and a half inches in a *minute*, whereas through the carotid artery of a dog it flies along at the rate of about ten inches in a *second*. Of course to complete the circuit of the circulation, a blood-corpuscle need not have to go through so much as half of an inch of capillaries in either the lungs or any of the tissues of the body.

Inasmuch as the force which drives the blood on is (putting the other comparatively slight helps on one side) the beat of the heart and that alone, however much it may be modified, as we have seen, in character, it is obvious that the velocity with which the blood moves must be greatest in the aorta and diminish towards the capillaries.

For with each branching of the arteries the total area of the arterial system is increased, the total width of the capillary tubes if they were all put together side by side being very much greater than that of the aorta. Hence the blood, or a corpuscle, for instance, of the blood being

en by the same force, viz. the heart's beat, over the le body, must pass much more rapidly through the than through the capillary system or any part of system.

is not that the greater friction in any capillary s the blood to flow more slowly there and there . The resistance caused by the friction in the llaries is thrown back upon the aorta, which indeed the resistance of the whole vascular system ; and it is total resistance which has to be overcome by the t before the blood can move on at all.

e blood driven everywhere by the same force simply es more and more slowly as it passes into wider and r channels. When it is in the capillaries it is slowest ; escaping from the capillaries, as the veins unite into r and larger trunks, and hence as the total venous is getting less and less, the blood moves again faster faster for just the same reason that in the arteries it ed slower and slower. It is, in fact, *the differences in width of the "bed,"* and this alone, which determines differences in the rate of flow at the various points of vascular system.

very similar case is that of a river widening out in in into a lake and then contracting into a narrow stream n. The water is driven by one force throughout (that ravity). The current is much slower in the lake than ne narrower river either before or behind.

4. The Nervous Control of the Arteries. Vaso-tor Nerves.—The arteries, as we have seen, are char-rised structurally by being elastic and muscular. In large arteries the elastic properties are more marked n the muscular, whereas in the smaller arteries the scular tissue is present in large amount relatively to elastic elements ; and we have dealt in detail with the ificance of arterial elasticity and its use in connection n the establishment of blood pressure and the dis-earance of the pulse. It has also been pointed out

(p. 34) that the small arteries may be directly affected by the nervous system, which controls the state of contraction of their walls, and regulates their calibre, and thus governs the supply of blood to each part of the body according to its varying needs. The control of the nervous system over the circulation in particular spots is of such paramount importance that we must now deal with this also in some detail.

A phenomenon with which every one is more or less familiar, either as experienced on themselves or observed on other persons, is that known as **blushing**. Now blushing is a purely *local* modification of the circulation, and it will be instructive to consider how a blush is brought about. An emotion, sometimes pleasurable, sometimes painful, takes possession of the mind; thereupon a hot flush is felt, the skin grows red, and according to the intensity of the emotion these changes are confined to the cheeks only, or extend to the "roots of the hair," or "all over."

What is the cause of these changes? The blood is a red and a hot fluid; the skin reddens and grows hot, because its vessels contain an increased quantity of this red and hot fluid; and its vessels contain more, because the small arteries suddenly dilate, the natural moderate contraction of their muscles being superseded by a state of relaxation; and this relaxation comes on because the action of the nervous system which previously kept the muscles in a state of moderate contraction is, for the time, suspended.

On the other hand, in many people, extreme terror or rage causes the skin to grow cold, and the face to appear pale and pinched. Under these circumstances, in fact, the supply of blood to the skin is greatly diminished, in consequence of an increased contraction of the muscles of the small arteries whereby these become unduly narrowed or constricted, and thus allow only a small quantity of blood to pass through them; and this increased con-

tion of the muscular coats of the arteries is brought
ut by the increased action of the nervous system.[1]
hat this is the real state of the case may be proved
rimentally upon rabbits. These animals may be
e to blush artificially. If, in a rabbit, the **sym-**
hetic nerve (Fig. 22, *C. Sy.*), which sends branches
e vessels of the head is cut, the ear of the rabbit,
h is covered by so delicate an integument that the
ges in its vessels can be readily perceived, at once
nes. That is to say, the vessels dilate, fill with blood,
the ear becomes red and hot. The reason of this is,
when the sympathetic is cut, the nervous impulse
h is ordinarily sent along its branches is interrupted,
the muscles of the small vessels, which were pre-
sly slightly contracted, become altogether relaxed.
d now it is quite possible to produce pallor and cold
e rabbit's ear. To do this it is only necessary to
ate the cut end of the sympathetic which remains
ected with the vessels. The nerve then becomes
ed, so that the muscular fibres of the vessels are
wn into a violent state of contraction, which di-
shes their calibre so much that the blood can hardly
e its way through them. Consequently, the ear
mes pale and cold.

his experiment on the blood-vessels of the rabbit's ear
fundamental importance as proof of the existence of
es which control locally the muscular elements of the
s of the smaller arteries ; and inasmuch as this con-
consists in causing *movements* of the walls of the
ls, by means of which their calibre is regulated, the
es which exert the control receive the general name
aso-motor nerves. But from the fact that when
cut end of the sympathetic nerve is irritated, or, as
physiologist says, is "stimulated," the muscular walls

[1] udden paleness is perhaps most frequently due to a failure or
age of the heart's beat, as in fainting. But it may also be observed
there is no change in the beat of the heart.

of the arteries with which it is connected are always contracted and the vessels themselves constricted, the sympathetic is more precisely characterised as a **vaso-constrictor nerve.** Further, since merely cutting the sympathetic leads to a dilation of the blood-vessels of the ear, we are justified in assuming that vaso-constrictor impulses are *continually being sent out* along this nerve, whereby the arteries are kept continually in a condition of slight or medium constriction. To this condition the name is given of **arterial "tone."** Now this "tone" is of great importance, for by its existence it at once becomes possible to increase the blood-supply to any part of the body as well as to diminish it. Did the arteries possess no "tone" they would, under ordinary resting conditions, be dilated to their full extent, and the part or organ they supply with blood would be receiving a maximum supply when at rest. But the organs of the body are never at rest for long, and when they become active they require an increased amount of blood which could not be supplied, at least by a vaso-constrictor mechanism, but for the existence of this arterial tone. It would of course be possible to increase the blood-supply by means of an increased activity of the heart ; but this would affect the supply to every part of the body at the same time, and what is really wanted is a localised variation in supply to meet the varying needs of each part or organ. Thus the vaso-constrictor nerves act by carrying *more* or *less* of the *same kind of impulse*, leading to increase or loss of tone and hence lessened or increased blood-supply ; they do not act, as is so frequently and erroneously imagined, by carrying one set or kind of impulses to produce constriction, and another set or kind to produce dilation.

We have quoted blushing as being a characteristic and familiar instance of the action of vaso-motor (vaso-constrictor) nerves. But other examples of exactly similar action are met with throughout the whole body. Thus when a muscle contracts, or when a salivary gland secretes

a, or when the stomach is preparing to digest food, ach case the small arteries of the muscle, salivary l or stomach, dilate and so flush the part with blood. organ in fact blushes ; and this inner unseen blush- s, like the ordinary blushing described above, brought by vaso-motor nerves. We shall see later on that temperature of the body is largely regulated by the y of blood sent to the skin to be cooled, and this ly is in turn regulated by the vaso-motor nervous m. Indeed everywhere all over the body, the ner- system by its vaso-motor nerves is continually super- g and regulating the supply of blood, sending now now less blood, to this or that part ; and many ses, such as those when exposure to cold causes con- on or inflammation, are due to, or at least associated , a disorder or failure of this vaso-motor activity.

The Vaso-motor Centre.—The vaso-constrictor es, which, by causing the varying contraction in the cular walls of the arteries, thus control the supply of l to each region of the body, can all be traced back e spinal cord. They make their exit from this part e central nervous system by the anterior roots of the l nerves of the middle part of the cord, and after ng through the ganglia of the sympathetic system Lesson XI.) are distributed to their various nations. The impulses which these nerves convey to lood-vessels are of course received by them from the al cord. This being the case the interesting question s as to where these impulses are generated before exit from the cord. Experiment shows that under nary circumstances they come down the cord from a t higher up, *i.e.* nearer the brain, than that at which nerves themselves pass off from the cord. In fact it been shown that they originate in a very limited ion of the central nervous system, located in that part which we shall describe in a later Lesson (XI.) as **spinal bulb** or **medulla oblongata**. Here then the

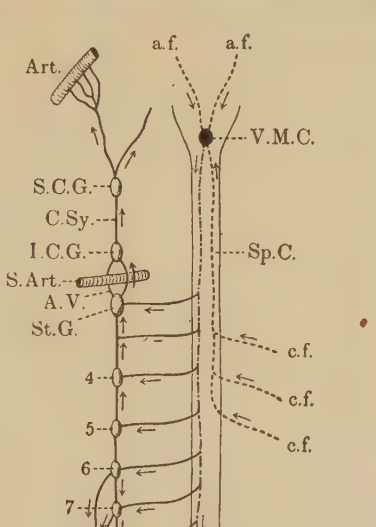
vaso-constrictor impulses are generated, and since they are the chief agents in determining the state of contraction or relaxation of the arteries of the body as a whole, this definitely localised part of the bulb has received the name of the **vaso-motor centre**. (Fig. 22, *V.M.C.*).

The cause of the phenomenon of arterial "tone" now becomes quite clear. The vaso-motor centre continually generates and sends out impulses to every part, or rather to very many parts, of the body, which suffice to keep the muscle fibres of the arteries supplying those parts in a condition of slight contraction. When the impulses are increased to any part, the supply of blood to that part is lessened; when the impulses are lessened the supply is increased.

But if the vaso-motor centre is to be of use it must itself be under the influence of impulses which can be made to play upon it in such a way as to determine those variations in its activity which are essential to its adapting itself to the varying needs of either the body as a whole or any small part of the body. These impulses which govern the vaso-motor centre pass into it either down from the brain above, or up from the spinal cord below. As an instance of the former case we may refer once again to "blushing." Here the emotion which leads to the blush, starts impulses in the brain which then pass down to the vaso-motor centre and modify its activity so as to lessen the intensity of the impulses it sends to the blood-vessels of the cheeks. As an instance of the second case we may refer to the effects of heat and cold applied to the body, as determining those variations of blood-supply to the skin by which the temperature of the body is so largely regulated (see Lesson V.). Here the impulses are started in the skin and, travelling along certain sensory nerves, enter the spinal cord, pass up to the vaso-motor centre, and as before lead to the necessary changes in its activity.

16. Vaso-dilator Nerves.—Our consideration of vaso-

or nerves has so far led us to the view that the dilation idening of an artery which leads to increased blood-



22.—Diagram to illustrate the Position of the Vaso-Motor Centre, the Paths of Vaso-Constrictor Impulses from the Centre along the Cervical Sympathetic Nerve and (part of) the Abdominal Splanchnic, and the Course of Impulses to the Centre from the Brain and from an outlying Part of the Body.

o.C., *Sp.C.* spinal cord ; *V.M.C.* vaso-motor centre ; *Art.* artery of ear ; *y.* cervical sympathetic ; *S.C.G.* superior cervical ganglion ; *I.C.G* rior cervical ganglion ; *S.Art.* subclavian artery ; *A.V.* annulus of ussens ; *St.G.* stellate ganglion ; 4, 5, 6, 7, 8, fourth, fifth, sixth, enth and eighth thoracic ganglia; *A.S.* upper roots and part of abinal splanchnic nerve. The dotted lines *a.f.*, *a.f.* indicate paths of duction for impulses to the vaso-motor centre from the brain. The ed lines *c.f.*, *c.f.*, *c.f.* indicate paths for the passage of impulses to the o-motor centre from some outlying part of the body such as the skin. arrows show the directions in which the impulses travel along a path.

supply is usually the result of cutting off or lessening constrictor impulses which were previously passing along the nerves to the arteries. But instances are met with in the body where the dilation is produced in an entirely different way. Thus there is a certain nerve called the **chorda tympani**, a branch of the facial or 7th cranial nerve (see Lesson XI.), which runs to the submaxillary salivary glands. When this nerve is simply severed, no obvious effect is produced on the blood-vessels of the gland. But if now the cut *end connected with the gland be stimulated*, the small arteries at once dilate powerfully, the blood-supply is enormously increased, and the gland becomes bright red and flushed. In this case we have to deal with a vaso-motor nerve whose typical behaviour when stimulated is, speaking broadly, the exact opposite to that of the vaso-constrictor nerves. It is in fact a vaso-motor nerve such that impulses passing along it give rise not to constriction but to dilation. Hence it is spoken of as a **vaso-dilator nerve.** Other instances of the occurrence of similar vaso-dilator nerves are met with, but as our knowledge of them is at present uncertain and incomplete we must be content with having simply drawn attention to their existence, and to one striking instance of their action. It will be observed that vaso-constrictor nerves only lead to dilation through interference with the vaso-motor centre and tonic impulses; vaso-dilator nerves bring about dilation directly.

17. **Nervous Control of the Heart. Cardiac Nerves.**—The heart, as we all know, is not under the direct influence of the will, but every one is no less familiar with the fact that the actions of the heart are wonderfully affected by all forms of emotion. Men and women often faint, and have sometimes been killed by sudden and violent joy or sorrow; and when they faint or die in this way, they do so because the perturbation of the brain gives rise to a something which arrests the heart as dead as you stop a stop-watch with a

ing. On the other hand, other emotions cause
extreme rapidity and violence of action which we
palpitation. These facts suggest at once that the
rt, like the arteries, is subject to control by the
tral nervous system, and we must now consider the
re important details of this control.

he heart is well supplied with nerves. There are
y small *ganglia*, or masses of nerve cells, lodged in
substance of the heart, more especially in the auricles,
nerves spread from these ganglia over the walls, both
he auricles and ventricles. Moreover, several nerves
ch the heart from the outside (Fig. 23). Of these the
st important are branches of a remarkable nerve which
rts from the spinal bulb, and supplies not only the
rt, but the lungs, alimentary canal, and other parts,
which is called the **pneumogastric**, or from its
ndering course, the **vagus** (see Lesson XI.). Other
ves reaching the heart seem to come from the sym-
thetic, but may be traced back through the sympathetic
the spinal cord, and, for reasons which will presently
come apparent, are called **accelerator nerves**.

he heart, as already explained (p. 51), contracts
thmically, but the regular rhythmical succession of the
inary contractions is not primarily dependent upon the
glia lodged in its substance, as was at one time
posed to be the case. Neither does it depend on the
ion of the nerves connected with the heart, since the
vements continue even after the heart is removed from
body. Hence we must conclude, and experiment
rs out the conclusion, that *the muscle substance of which
heart is made is itself endowed with the power of con-
cting and relaxing at regular intervals.* On the other
d the influences which alter the heart's action, as in
ting or palpitation, do as a rule come to the heart from
hout, and are carried to the heart along the vagus
accelerator nerves. This may be demonstrated on
mals, such as frogs, with great ease.

If a frog be pithed, or its brain destroyed, so as to obliterate all sensibility, the animal will continue to live, and its circulation will go on perfectly well for a prolonged period. The body may be laid open without causing pain or other disturbance, and then the heart will be observed beating with great regularity. It is possible to make the heart move a long lever backwards and forwards ; and if frog and lever are covered with a glass shade, the air under which is kept moist, the lever may vibrate with great steadiness for a couple of days.

It is easy to adjust to the frog thus prepared a contrivance by which electrical shocks may be sent through the vagus nerves, so as to stimulate them. If the stimulation is only gentle or weak, the heart will be seen to beat more slowly, and at the same time each beat is rather more feeble, as shown by the diminished distance over which the end of the lever moves. But if the stimulation is strong, the lever almost immediately stops dead, and the heart will be found quiescent, with relaxed and distended walls. After a little time the influence of the vagus passes off, the heart recommences its work as vigorously as before, and the lever vibrates through the same arc as formerly. With careful management, this experiment may be repeated very many times ; and after every arrest by the stimulation of the vagus, the heart resumes its work.

If on the other hand the stimulation be applied to the sympathetic nerves, then an effect is produced which is exactly the opposite to that which results from stimulating the vagus. The lever moves more rapidly and over a greater distance, showing quite clearly that the heart is now beating faster and that each beat is stronger.

No clearer proof could be desired than is afforded by the above experiments, that the heart of the frog is controlled by two antagonistic nerves of which one, the vagus, carries impulses which slow and finally stop its beat, while the other, the accelerator, conveys impulses

which make it beat faster. Since there is no reason for supposing that the working mechanisms of a frog's heart differ in any essential way from those of the mammalian heart, we may at once apply these striking results to the human heart. It is, in fact, recorded of a certain well-known physiologist, that having a small hard tumour in his neck, in close proximity to the vagus nerve, he could press the vagus against this tumour and by thus stimulating it mechanically cause a stoppage of his own heart-beat.

The heart, then, is controlled by two kinds of antagonistic influences, analogous to those previously described as controlling the muscular walls of the arteries. Moreover both the cardiac nerves are connected with the central nervous system, the one coming from the spinal bulb, the other from the spinal cord, so that the influences they convey to the heart must, as in the case of the vaso-motor nerves, originate in the central nervous system. We saw, however (p. 69), that the impulses carried by the vaso-motor nerves are generated in a very specially localised part of the spinal bulb, and the interesting question at once arises : Is there a similarly localised centre in which the impulses which modify the beat of the heart take their origin ? The answer to this question is in the affirmative, for experiment shows that the impulses which, travelling along the vagus, can stop or, as the physiologist says "inhibit," the heart's beat, are generated in a limited part of the spinal bulb, in close proximity to the vaso-motor centre. This part is therefore known as the **cardio-inhibitory centre.** There are reasons for supposing that this centre, like the vaso-motor centre, is continually at work sending out impulses to the heart along the vagus, which check its activity, so that in many animals the heart beats more quickly after the vagus nerves are cut.

The cardio-inhibitory centre may, like the vaso-motor centre. be itself influenced by impulses which reach it

either from the brain above or the spinal cord below. In this way the heart is indirectly connected with all parts of the body, so that by nervous agencies its beat may be

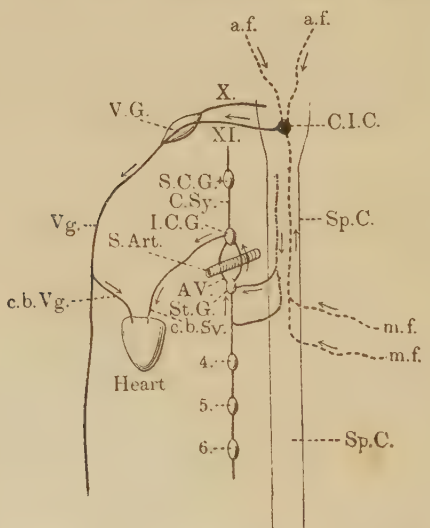


FIG. 23.—DIAGRAM TO ILLUSTRATE THE POSITION OF THE CARDIO-INHIBITORY CENTRE, THE PATHS OF INHIBITORY AND ACCELERATOR IMPULSES FROM THE CENTRAL NERVOUS SYSTEM TO THE HEART, AND THE COURSE OF IMPULSES TO THE CENTRE FROM THE BRAIN AND FROM AN OUTLYING PART OF THE BODY.

Sp.C., *Sp.C.* spinal cord; *C.I.C.* cardio-inhibitory centre; *X.* vagus nerve at its origin; *V.G.* ganglion of the vagus, through which run the fibres coming from the centre along *XI.* the spinal accessory nerve (see Lesson XI.). *Vg.* main trunk of the vagus; *c.b.Vg.* cardiac branches of vagus, supplying the heart; *C.Sy.* sympathetic nerve in the neck; *S.C.G.* superior cervical ganglion; *I.C.G.* inferior cervical ganglion; *S.Art.* subclavian artery; *A.V.* annulus of Vieussens; *St.G.* stellate ganglion; 4, 5, 6, fourth, fifth and sixth thoracic ganglia; *c.b.Sy.* cardiac branches of the sympathetic supplying the heart. The dotted lines *a.f.*, *a.f.* indicate paths of conduction for impulses to the cardio-inhibitory centre from the brain. The dotted lines *m.f.*, *m.f.* indicate paths for the passage of impulses to the cardio-inhibitory centre from some outlying part of the body such as the stomach or intestines. The arrows show the directions in which the impulses travel along each path.

ade to vary according to the varying needs of the body
a whole or of its several parts. For instance when
king exercise, the restraining influence of the centre is
ened and the heart beats faster, thus providing for an
creased rapidity of the circulation to meet the demands
f the more actively contracting muscles. It is of course
ssible that the faster beat of the heart may also be due
impulses along the accelerator nerves. Again when a
rson faints from a sudden emotion, an influence is
rted in the brain, passes down to the centre in the
inal bulb, *increases* its action and stops for a time the
ating of the heart. Or again, fainting may result from
blow on the stomach ; in this case the influence starts
the part struck, and passing up the spinal cord to the
rdio-inhibitory centre, increases its activity and leads as
fore to stoppage of the heart. The rapid and violent
eating of the heart which we speak of as "palpitation"
ay on the other hand be often due to some emotion
hich in this case *lessens* the activity of the centre and
ence diminishes the restraint which it ordinarily exerts
er the heart. But of course palpitation may also at
mes be due to impulses reaching the heart along those
rves which we have described above as the accelerators.

Our knowledge of the existence and position of the
rdio-inhibitory centre is quite clear and definite. It is
ossible that a cardio-augmentor (-accelerator) centre may
lso exist, but at present we have no exact knowledge of
s existence ; hence in the accompanying figure (Fig. 23)
he accelerator nerves are shown as originating in the
entral nervous system, but not arising from any de-
nitely localised centre.

18. The Proofs of the Circulation.—The evidence
hat the blood circulates in man, although perfectly con-
lusive, is almost all indirect. The most important points
n the evidence are as follows :—

In the first place, the disposition and structure of the
rgans of circulation, and more especially the arrange-

ment of the various valves, will not, as was shown by Harvey, permit the blood to flow in any other direction

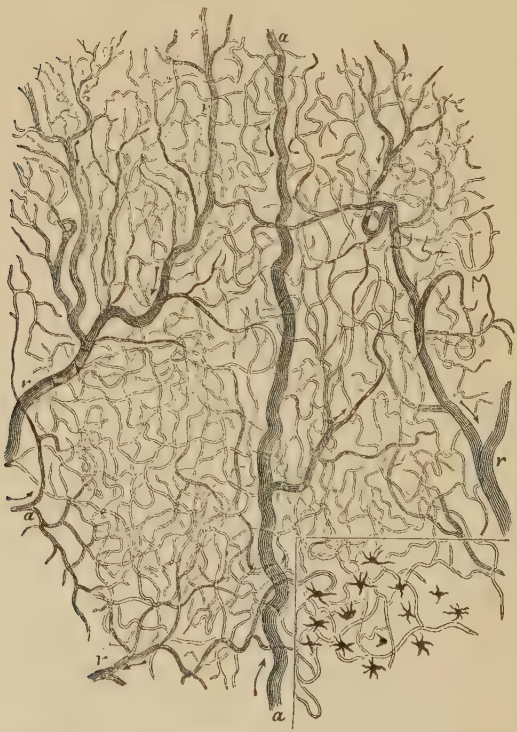


FIG. 24.—PORTION OF THE WEB OF A FROG'S FOOT SEEN UNDER A LOW MAGNIFYING POWER, THE BLOOD-VESSELS ONLY BEING REPRESENTED, EXCEPT IN THE CORNER OF THE FIELD, WHERE IN THE PORTION MARKED OFF THE PIGMENT SPOTS ARE ALSO DRAWN.

a, small arteries; *v*, small veins; the minute tubes joining the arteries of the veins are the capillaries. The arrows denote the direction of the circulation. The larger artery running straight up in the middle line breaks up into capillaries at points higher up than can be shown in the drawing.

m in the one described above. Moreover, we can ily with a syringe inject a fluid from the vena cava, for tance, through the right side of the heart, the lungs, left side of the heart, the arteries, and capillaries, back the vena cava ; but not the other way. In the second ce, we know that in the living body the blood is con- ually flowing in the arteries towards the capillaries, ause when an artery is tied, in a living body, it swells and pulsates on the side of the ligature nearest the art, whereas on the other side it becomes empty, and e tissues supplied by the artery become pale from the nt of a supply of blood to their capillaries. And when cut an artery the blood is pumped out in jerks from e cut end nearest the heart, whereas little or no blood mes from the other end. When, however, we tie a vein e state of things is reversed, the swelling taking place the side farthest from the heart, &c. &c., showing that the veins the blood flows from the capillaries to the art.

But certain of the lower animals, the whole, or parts, the body of which are transparent, readily afford direct oof of the circulation ; in these the blood may be seen shing from the arteries into the capillaries, and from the pillaries into the veins, so long as the animal is alive nd its heart is at work. The animal in which the circu- tion can be most conveniently observed is the frog. he web between its toes is very transparent, and the orpuscles suspended in its blood are so large that they can e readily seen as they slip swiftly along with the stream f blood, when the toes are fastened out, and the inter- ening web is examined under a microscope (Fig. 24).

19. **The Capillary Circulation.**—The essential charac- eristics of blood-flow through the capillaries may be asily studied by observation under the microscope of the web of a frog's foot. In the smallest capillaries the cor- puscles pass along singly, sometimes following each other n close file, at other times leaving quite considerable

gaps in their succession. Frequently one or more corpuscles may remain stationary for a moment and then pass on again. The red corpuscles, which in the frog are oval and comparatively large, glide along with their long axis parallel to the direction of the stream, and may often be observed to be squeezed out of shape by pressure against the wall of the capillary (Fig. 25, *G* and *H*). In the larger capillaries, more especially in mammals whose corpuscles are smaller than in the frog, the corpuscles often pass along two or three abreast. Further, in these larger capillaries it may be seen that the red corpuscles tend to keep to the centre of the stream, leaving a clear layer of fluid along the sides of the blood-vessels. This is due to the fact that the fluid friction (already referred to on p. 56) is greater close to the walls of the capillaries than in the middle of the stream, and the corpuscles pass along where the resisting friction is least. The colourless or "white" corpuscles usually move more slowly and irregularly than the red, and may, as a rule, be seen to lie in the clearer layer of fluid at the side of the current. Moreover, they frequently stop for an appreciable time, as if sticking to the wall of the capillary, and then roll on again; probably because they are more adhesive than the red corpuscles as a result of their power of executing amœboid movements (see p. 100).

20. Inflammation.—Everybody is more or less familiar with a peculiar and unusual condition which may arise in almost any part of the body, and which they describe by speaking of the part as "inflamed." To ordinary observation the characteristics of the condition are that the inflamed region becomes flushed and red, that it feels warmer than usual, that it becomes swelled and painful, and finally, if the inflammation is severe, that a thick yellowish fluid is formed which is commonly known as "matter," or more correctly as **pus**. Such a series of changes may be observed during the formation and breaking of a boil. But the several stages just named are

FIG. 25.—VERY SMALL PORTION OF FIG. 24 VERY HIGHLY MAGNIFIED.

A, walls of capillaries; *B*, tissue of web lying between the capillaries; cells of epidermis covering web (these are only shown in the right-and and lower part of the field; in the other parts of the field the focus the microscope lies below the epidermis); *D*, nuclei of these epidermic lls; *E*, pigment cells contracted, not partially expanded as in Fig. 23; red blood-corpuscle (oval in the frog) passing along capillary—nucleus t visible; *G*, another corpuscle squeezing its way through a capillary, ne canal of which is smaller than its own transverse diameter; *H*, nother bending as it slides round a corner; *K*, corpuscle in capillary een through the epidermis; *I*, white blood-corpuscle.

merely the external evidences of changes taking place at the same time in the minute blood-vessels and circulation of the part affected, and since these changes throw an interesting light on the relations ordinarily existing between the walls of the blood-vessels and the neighbouring blood, they are worthy of a short consideration.

If when the web of a frog's foot, or other suitably transparent part of an animal, is adjusted for observation under the microscope, some irritant be applied to it such as a trace of mustard,[1] the following events may be readily observed. The minute arteries dilate, the blood flows faster, and the increased quantity of blood forced through the capillaries distends them so that they, as well as the smallest veins, appear to be similarly dilated. This accounts for the initial greater redness and warmth of an inflamed part. Very soon the colourless corpuscles are seen to be collecting in large numbers in the clear layer of fluid next to the walls of the capillaries and veinlets, and seem to adhere more firmly than usual to the walls of these vessels. Further, blood "platelets" (see p. 104), not previously visible, begin to collect also with and among the white corpuscles. Following upon this the stream of blood begins to flow more slowly although the blood-vessels are still widely dilated. And now a very striking phenomenon takes place. The white corpuscles make their way by amœboid movements through the thin walls of the capillaries and collect outside them in the spaces in the neighbouring tissue. At the same time that the corpuscles are in this way "migrating," a considerable quantity of the fluid part of the blood also passes out through the walls of the blood-vessels into the adjacent tissue. This accounts for the characteristic swelling of an inflamed part. If the action of the irritant is continued, more and more white corpuscles collect in the vessels, the blood-flow becomes slower and slower,

[1] Used similarly as an irritant in the form of the ordinary domestic mustard poultice.

corpuscles are arrested in large numbers among the
e, and finally the circulation stops altogether. At
stage red corpuscles pass through the walls of the
els as well as the white, and the latter multiplying
dly in the spaces of the tissue outside the blood-
els, and undergoing certain other slight changes, are
erted into pus corpuscles.

he appearances just described seem to indicate that
ondition of the walls of the capillaries (and of the
llest veins and arteries) plays a very important part
etermining the characteristics of the normal circulation
ugh these passages. And since in an inflamed area
flow of blood becomes slower and slower, and ulti-
ely ceases, even while the blood-vessels are more
ely dilated than usual, the condition of the walls of
e vessels may evidently play a very important part in
rmining variations in that "peripheral resistance"
h, as we have previously explained, is of paramount
ortance to the working of the circulation throughout
y part of the whole body. Moreover it is evident
the condition of the walls of the capillaries may also
ny moment modify the amount of the fluid part of the
d which is continually passing out through those
s as lymph (p. 84) for the nutrition of the neigh-
ing tissues.

T II.—The Lymphatic System and the Circulation of Lymph

The General Arrangement of the Lymphatics.—
l, as we have already pointed out (p. 23), after
stion in the alimentary canal, is absorbed into the
d-vessels and lacteals of that canal and whirled away in
current of the circulation for distribution as nutritive
erial to all parts of the body. But we have also
n attention to the fact (p. 31) that the ultimate

anatomical components, the cells and tissues, of every part of the body lie *outside* the blood-vessels. It is therefore clear that the tissues are everywhere separated from the blood by at least the thickness of the walls of the vessels, and in any case cannot draw the nutriment they require directly from the blood, since they are nowhere in direct contact with it. Neither can they, for the same reason, discharge the waste they are always producing directly into the blood for its removal as a preliminary to its excretion. Both these difficulties are however got over by the fact that *a portion of the fluid part of the blood is continually exuding through the walls of the capillaries* into the neighbouring tissues, taking with it the nutriment necessary for each tissue and providing a fluid connection between the tissue and the blood across which the waste from the tissues can be returned into the blood. The fluid which thus exudes is called **lymph**,[1] and may be regarded as a sort of "middleman" between the blood on the one hand and the tissue on the other. But if now this lymph is to be thoroughly efficient as a nutriment for the tissues it should presumably contain more food material than the tissues actually require as an average, and it must therefore be an economy to the body if the lymph, after having served the needs of the tissues, is gathered up again and returned to the blood for further use. Now this is exactly what does take place, and the means for ensuring the return of the lymph to the blood-vessels are as follows.

Besides the capillary network and the trunks connected with it which constitute the blood-vascular system, all parts of the body which possess blood capillaries also contain another set of what are termed **lymph-capillaries**, mixed up with those of the blood-vascular system, but not directly communicating with them, and, in addition differing from the blood-capillaries in being

[1] The mode of formation, composition and properties of lymph are dealt with in Lesson III.

nected with larger vessels of only one kind. t is to say they open only into trunks which carry l away from them, and thus bear the same relationship to lymph-capillaries that the veins do to blood-capillaries. se trunks are known as the **lymphatic vessels**, further resemble the small veins he general structure of their walls in being abundantly provided h valves, similar to those in the s, which freely allow of the passage ymph from the lymph-capillaries, obstruct the flow of any liquid in opposite direction. But the lym-tic vessels differ from the veins in t they do not rapidly unite into ger and larger trunks which present continually increasing calibre and w a flow without interruption to heart. On the contrary, remaining rly of the same size, they at intervals come connected with small rounded often bean-shaped bodies called **mphatic glands**, entering the nds at one side and emerging at opposite side as new lymphatic sels (Fig. 26, *g.*).

FIG. 26.—THE LYMPHATICS OF THE FRONT OF THE RIGHT ARM.

g, lymphatic glands, on the course of the lymphatics.

Sooner or later the great majority of smaller lymphatic vessels pour their ntents into a tube which is about as ge as a goose-quill, lies in front of backbone, and is called the **thor-ic duct.** This opens at the root the neck into the conjoined trunks the great veins (jugular and sub-avian) which bring back the blood from the *left* side the head and the *left* arm. (Fig. 27, *f.g.*)

The remaining lymphatics, chiefly those of the right

side of the head and neck, the right arm and right lung, are connected by a common canal with the corresponding vein of the right side.

The lower part of the thoracic duct is dilated, and is called the **receptacle of the chyle** (Fig. 27, *a*.). This part receives more particularly the lymphatics from the intestines, which, though they differ in no essential respect from other lymphatics, are called **lacteals**, because, after a meal containing much fatty matter, they are filled with a *milky* fluid termed **chyle**. The lacteals, or lymphatics of the small intestine, not only form networks in its walls, but send blind prolongations into the little processes termed **villi**, with which the mucous membrane of that intestine is beset. (See Lesson VI.)

Where the two principal trunks of the lymphatic system open into the veins, valves are placed which allow of the passage of fluid in one direction only, namely from the lymphatic to the veins, the blood in the veins being unable to get into the lymphatics, and in this way the lymph from every part of the body is collected and returned into the blood.

2. **The Origin and Structure of Lymphatics.**—The tissues of the body are built up of cells which, though lying closely applied to each other, are often separated by extremely minute spaces. These spaces are particularly plentiful in that form of tissue of which we have already spoken as connective tissue, as a result of its structural arrangement, for it is made up of bundles of fine threads or fibres which cross one another in all directions and thus form a sort of feltwork of interlacing fibres. Some of the spaces in this tissue are comparatively large and are called areolæ, whence this particular kind of connective tissue is sometimes called **areolar tissue** (see Lesson XII.). This areolar tissue is, as we have said (p. 13), present in every part of the body, and of course supports the blood-capillaries, which are thus, in reality, merely minute tubes lying imbedded in connective tissue.

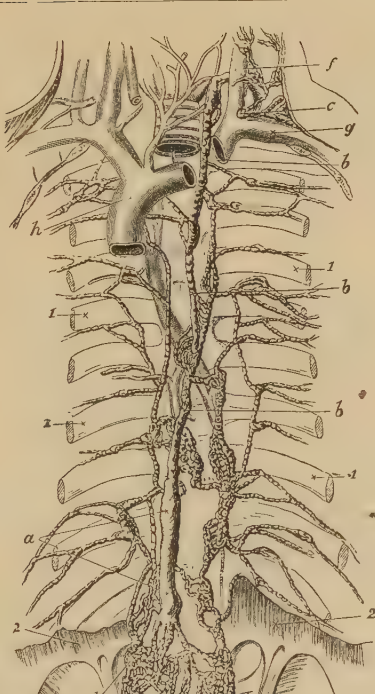


FIG. 27.—THE THORACIC DUCT.

The Thoracic Duct occupies the middle of the figure. It lies upon the spinal column, at the sides of which are seen portions of the ribs (1). *a*, the receptacle of the chyle; *b*, the trunk of the thoracic duct, opening at *c* into the junction of the left jugular (*f*) and subclavian (*g*) veins as they unite into the left innominate vein, which has been cut across to show the thoracic duct running behind it; *d*, lymphatic glands placed in the lumbar regions; *h*, the superior vena cava formed by the junction of the right and left innominate veins.

The chinks and spaces of the tissues are filled with that fluid exudation from the blood-vessels and tissue elements already spoken of as lymph, and hence are themselves often called **lymph-spaces.** In these lymph-spaces we see the origin or beginning of the lymphatic system.

From the lymph-spaces the lymph passes into the lymph capillaries. These are also essentially spaces in the mesh-

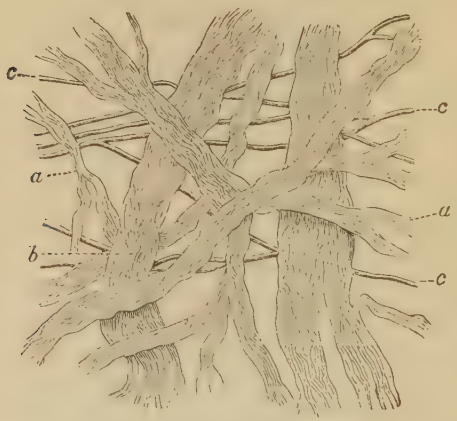


Fig. 28.—Connective Tissue Fibres.

a, small bundles of white fibrous tissue; *b*, larger bundles; *c*, single elastic fibres.

work of connective tissue, but they are now lined by a single layer of extremely thin, flat, nucleated, epithelioid cells, very similar to those composing the wall of a blood capillary, but characterised by their edges being very sinuous or indented. These cells are joined to each other by their edges, the sinuosities of adjacent cells fitting into one another, so that they form a system of minute tubes, larger than blood-capillaries and wandering more irregularly.

The **lymphatic vessels** into which the lymph-pillaries pour their contents on its way towards the racic duct possess a structure essentially similar to of a vein (p. 34); but they differ from a vein in that r walls are thinner, so thin as to be very transparent, *relatively* more muscular and are more plentifully plied with valves, whose structure, however, is the e as in the veins.

29.—Epithelioid Cells Lining, and Characteristic of, the Lymphatics.

outline of the cells has been brought into view by means of te of silver, which does not stain the nuclei; the latter therefore not shown.

The Structure and Function of Lymphatic nds.—Lymphatic glands occur at more or less frequent rvals along the course of the lymphatic vessels. They of very variable size, being somewhat rounded when ll and when large having more or less the shape of a n. The afferent lymphatic vessels enter the glands several branches on its more convex side, and emerge liminished numbers as efferent vessels from the opposite . Blood-vessels enter and leave the glands side by with the efferent lymphatic vessels.

Each gland is covered externally by a **capsule** or coat connective tissue, with which some unstriated muscle es are not infrequently mixed. This capsule sends jections, called **trabeculæ**, inwards and towards the tre of the gland which divide it up into compartments **alveoli**, the compartments being very regularly ar-ged at the outer portion or **cortex** of the gland and

irregularly in the more central parts or **medulla** (see Fig. 30). Each alveolus is filled with a network of connective tissue, whose meshes are small and closely set in the central part of the alveolus, wider or more open when in contact with the trabeculæ. The central small meshed network is known as **adenoid tissue,**[1] is densely packed

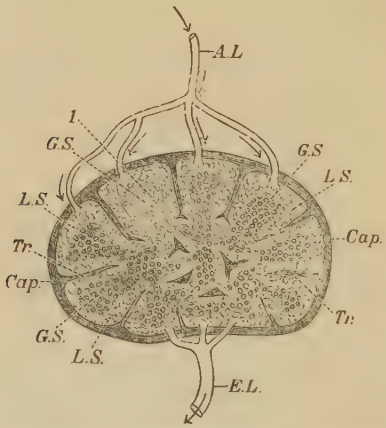


FIG. 30.—DIAGRAMMATIC REPRESENTATION OF A LYMPHATIC GLAND SEEN IN SECTION. (AFTER SHARPEY.)

Cap. capsule; *Tr.* trabeculæ; *G.S.* glandular substance: *L.S.* lymph sinus. In the alveolus marked 1. all the leucocytes are supposed to have been washed out; in the rest of the gland they are shown in the glandular substance, but washed out of the lymph-sinuses. *A.L.* afferent lymphatic; *E.L.* efferent lymphatic. The arrows show the direction in which the lymph enters and leaves the gland.

with lymph-corpuscles or **leucocytes** closely resembling the colourless corpuscles of blood (p. 100), and constitutes what is usually spoken of as the **glandular substance.** The more open-meshed network which surrounds the glandular substance and separates it from the trabeculæ

[1] Also often called *retiform* or *lymphoid* connective tissue. (See Lesson XII.)

known as the **lymph-sinus** or **lymph-channel.** ...e meshes of the lymph-sinus, like those of the glandular ...bstance, are crowded with leucocytes, but these are not ...y firmly fixed in this network as they are in that of ... glandular substance, and may be readily washed out ... shaking a thin slice of the gland in water.

The lymphatic vessels which bring lymph to the gland ...n directly into the channel of the lymph-sinus, and ...se vessels which gather up the lymph to carry it away ...m the gland open out of the lymph-sinuses. The ...eries supplying blood to the gland pass along the ...beculæ, cross the lymph-sinus, enter the glandular sub...ance and break up into a network of capillaries from ...ich the blood is collected and carried away by small ...ins.

The leucocytes which crowd the glandular substance ...sent under the microscope appearances which leave no ...ubt that they are undergoing rapid and probably large ...crease in numbers. But since the size of each gland is ...dinarily constant, a continual removal of the newly ...med leucocytes must be taking place. This view is ...ne out by the observation that leucocytes are more ...merous in the lymph coming from a gland than in that ...ich flows to it. The removal takes place by a discharge ...eucocytes from the glandular substance into the meshes ... the neighbouring lymph-sinus, whence they are then ...shed away in the current of lymph which is always ...wly flowing through the sinuses. In this way the ...mphatic glands provide a constant supply of leucocytes ...ich are passed ultimately into the blood and become ...se white or colourless corpuscles with which we shall ...ve to deal in the next Lesson.

4. Causes which lead to the Movements of Lymph.

Throughout the preceding description of the lymphatic ...stem we have spoken of the lymph as flowing along a ...ries of passages, from their origin in the tissues to the ...int where they become connected with the blood-vessels.

The cause of this flow is not so immediately apparent as it is in the case of the blood, for the lymphatic system possesses no central pump, such as the heart, to keep the lymph in motion.[1] In the absence then of any obviously propulsive mechanism, to what may we attribute this continual passage of lymph along the lymphatics?

The flow is in reality brought about by several causes. We may point out in the first place that some force, whose nature will be considered in the next Lesson, is at work to determine the initial exit of fluid from the blood-vessels into the lymph-spaces. This force must obviously tend to drive out the lymph already in those spaces, into and along the channels leading from them. Further, as we have seen, the blood-pressure in the large veins near the heart is very small and is certainly much less than it is in the capillaries; and since the lymphatics originate at the capillaries and discharge their contents into the great veins, this difference of pressure at the two ends of the system must tend to cause an onward flow of lymph. Here also the movements of respiration play a part, for, as will be seen when dealing with respiration, the pressure in the great veins is suddenly diminished at each inspiration and lymph is thus sucked out of the thoracic duct, no reversal of this action being possible at expiration because of the valves guarding the end of the duct. But the one great and potent cause of lymph-flow is the presence, all along the course of the lymphatics, of valves whose action is, however, only brought into play by the movements of the body. As in the veins (p. 36) so in the lymphatic vessels; when any pressure is applied to their outside the lymph is driven out of the squeezed part, and since the valves only open towards the junction of the thoracic duct with the venous system, the lymph is thereby driven along in the desired direction.

[1] The frog possesses four lymph hearts, placed in two pairs at the upper and lower end of the backbone. Their structural arrangement is very similar to that of the blood-heart, and, being rhythmically contractile, they pump the lymph into the venous system.

LESSON III

THE BLOOD AND THE LYMPH

Microscopic Examination of Blood.—In order to ome properly acquainted with the characters of the od it is necessary to examine it with a microscope gnifying at least three or four hundred diameters. vided with this instrument, a hand lens, and some s of thick and thin glass,[1] the student will be enabled follow the present lesson.

he most convenient mode of obtaining small quantities blood for examination is to twist a piece of string, ty tightly, round the middle of the last joint of the dle, or ring finger, of the left hand. The end of the er will immediately swell a little, and become darker ured, in consequence of the obstruction to the return he blood in the veins caused by the ligature. When his condition, if it be slightly pricked with a sharp n needle (an operation which causes hardly any pain), od-sized drop of blood will at once exude. Let it be osited on one of the slips of thick glass, and covered tly and gently with a piece of the thin glass, so as to ead it out evenly into a thin layer. Let a second slide ive another drop, and, to keep it from drying, let it put under an inverted watch-glass or wine-glass, with it of wet blotting-paper inside. Let a third drop be lt with in the same way, a few granules of common being first added to the drop.

[1] Slides and coverslips, as they are called by microscopists.

To the naked eye the layer of blood upon the first slide will appear of a pale reddish colour, and quite clear and homogeneous. But on viewing it with even a pocket lens its apparent homogeneity will disappear, and it will look like a mixture of excessively fine yellowish-red particles, like sand, or dust, with a watery, almost colourless, fluid. Immediately after the blood is drawn, the particles will appear to be scattered very evenly through the fluid, but by degrees they aggregate into minute patches, and the layer of blood becomes more or less spotty.

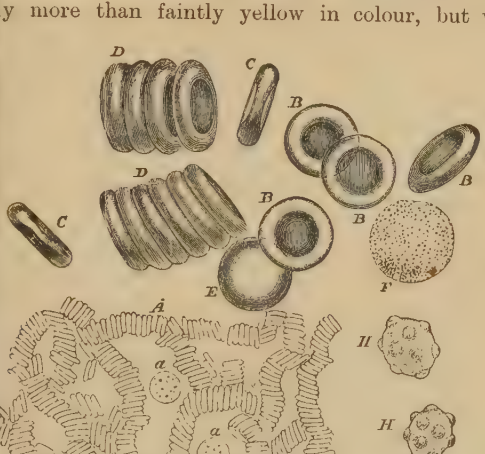
The "particles" are what are termed the **corpuscles** of the blood; the nearly colourless fluid in which they are suspended is the **plasma**.

The second slide may now be examined. The drop of blood will be unaltered in form, and may perhaps seem to have undergone no change. But if the slide be inclined, it will be found that the drop no longer flows; and, indeed, the slide may be inverted without the disturbance of the drop, which has become solidified, and may be removed, with the point of a penknife, as a gelatinous mass. The mass is quite soft and moist, so that this setting, the **clotting** or **coagulation**, of a drop of blood is something very different from its drying.

On the third slide, this process of clotting will be found not to have taken place, the blood remaining as fluid as it was when it left the body. The salt therefore has prevented the coagulation of the blood. Thus this very simple investigation teaches that blood is composed of a nearly colourless plasma, in which many coloured corpuscles are suspended; that it has a remarkable power of clotting; and that this clotting may be prevented by artificial means, such as the addition of salt.

If, instead of using the hand lens, the drop of blood on the first slide be placed under the microscope, the particles, or corpuscles, of the blood will be found to be bodies with very definite characters, and of two kinds, called respectively the **red corpuscles** and the **white**

colourless corpuscles. The former are much numerous than the latter, and have a yellowish-red ; when one of these corpuscles is seen, under a high r of the microscope, lying by itself, it seems to be ly more than faintly yellow in colour, but when



IG. 31.—Red and White Corpuscles of the Blood Magnified.

Moderately magnified. The red corpuscles are seen lying in aux ; at *a* and *a* are seen two white corpuscles.
Red corpuscles much more highly magnified, seen in face ; *C.* ditto, in profile ; *D.* ditto, in rouleaux, rather more highly magnified ; *E.* a orpuscle swollen into a sphere by imbibition of water.
A white corpuscle magnified same as *B.*
Red corpuscles puckered or crenate all over.
Ditto, at the edge only.

ral are seen lying one on the other, the redness omes obvious. The white, somewhat larger than the corpuscles, are, as their name implies, pale and devoid olouration.

The corpuscles differ also in other and more important respects.

2. **The Red Corpuscles.**—The red corpuscles (Fig. 31) are flattened circular discs, on an average 7μ to 8μ ($\frac{1}{3200}$ of an inch) in diameter, and having about one-fourth of that thickness. It follows that rather more than 10,000,000 of them will lie on a space one inch square, and that the volume of each corpuscle does not exceed $\frac{1}{120000000000}$th of a cubic inch.

The broad faces of the discs are not flat, but somewhat concave, as if they were pushed in towards one another. Hence the corpuscle is thinner in the middle than at the edges, and when viewed under the microscope, by transmitted light, looks clear in the middle and darker at the edges, or dark in the middle and clear at the edges, according as it is or is not in focus. When, on the other hand, the discs roll over and present their edges to the eye, they look like rods. All these varieties of appearance may be made intelligible by taking a small, round, flat disc of clay or putty and squeezing the central part of the two flat sides between the thumb and finger, so as to make the centre thinner than the edges ; the disc is now more or less similar in shape to the red corpuscles, and may be turned into various positions before the eye.

In a drop of blood immediately after it is drawn, the red corpuscles float about and roll, or slide, over each other quite freely. After a short time (the length of which varies in different persons, but usually amounts to two or three minutes), they seem, as it were, to become sticky, and tend to cohere ; and this tendency increases until, at length, the great majority of them become applied face to face, so as to form long series, like rolls of coin. The end of one roll cohering with the sides of another, a network of various degrees of closeness is produced (Fig. 31, *A.*).

The corpuscles remain thus coherent for a certain length of time, but eventually separate and float freely

n. The addition of a little water, or dilute acids aline solutions, will at once cause the rolls to k up.

is from this running together of the corpuscles into hes of network that the change noted above in the arances of the layer of blood, viewed with a lens, s. So long as the corpuscles are separate, the sandy arance lasts ; but when they run together, the layer ears patchy or spotted.

he red corpuscles, rarely, if ever, all run together into , some always remaining free in the meshes of the In contact with air, or if subjected to pressure, y of the red corpuscles become covered with little bs, so as to look like minute mulberries—an appear- which is due to the concentrating by evaporation of fluid in which they are floating (Fig. 31, *H*, *H*.).

he red corpuscles are very soft, flexible, and elastic es, so that they readily squeeze through apertures and sages narrower than their own diameters, and imme- ely resume their proper shapes (Fig. 25, *G*, *H*.). mined under even a high power the red corpuscle ents no very obvious structure ; when however blood ozen and thawed one or more times, or when it is ted in certain other ways, as, for instance, by the tion of water, the colouring matter which gave each uscle its yellow or yellowish-red tinge is dissolved out passes into the surrounding fluid, and all that is left he corpuscle is a colourless framework appearing often er the microscope as a pale, hardly visible, ring. h corpuscle in fact consists of a sort of spongy colour- framework, the **stroma**, composed of the kind of erial known as **proteid** and of a peculiar colouring ter, which, in the natural condition, is intimately nected with this framework, but may by appropriate ns be removed from it. This colouring matter, which f a highly complex nature, is called **hæmoglobin**, may by proper chemical treatment be resolved into a

reddish-brown substance containing iron, called **hæmatin**, and a colourless proteid substance.

Each corpuscle therefore is not to be considered as a bag or sack with a definite skin or envelope containing fluid, but rather as a sort of spongy semi-solid or semi-fluid mass, like a disc of soft jelly ; and as such is capable of imbibing water and swelling up, or giving out water and shrinking according to the density of the fluid in which it may be placed. Thus, if the plasma of blood be made denser by dissolving saline substances, or sugar, in it, water is drawn from the substance of the corpuscle to the dense plasma, and the corpuscle becomes still more flattened and very often much wrinkled. On the other hand, if the plasma be diluted with water, the latter forces itself into and dilutes the substance of the corpuscle, causing the latter to swell out, and even become spherical ; and, by adding dense and weak solutions alternately, the corpuscles may be made to become successively spheroidal and discoidal. Exposure to carbonic acid gas seems to cause the corpuscles to swell out ; oxygen gas, on the contrary, appears to flatten them.

The stroma or framework constitutes but a very small part, 10 per cent., of the solid matter of which the red corpuscles are composed, the remaining 90 per cent. consisting of the colouring matter or hæmoglobin. The corpuscles may therefore be regarded as simply so many tiny masses of hæmoglobin. Now hæmoglobin, we may say at once, possesses the remarkable property of uniting in a peculiar way with considerable quantities of oxygen, and thus confers on the red corpuscles their one great characteristic of acting as the carriers of oxygen from the lungs to the tissues of all parts of the body. We have already pointed out (p. 25) the general importance of this transference of oxygen to the tissues ; the details connected with the relationship of hæmoglobin to this transference may be more appropriately dealt with when we study respiration in the next Lesson.

The colouring matter of the corpuscles is further racterised by its property of crystallising more or less dily. If a little rat's or dog's blood, from which the in has been removed (see below) be shaken up with a ll quantity of ether, it loses its opacity and becomes te transparent in thin layers, or as it is often called y.' The transparency results from the discharge of hæmoglobin from the stroma into the neighbouring d, in which it is now in solution. If the vessel con-

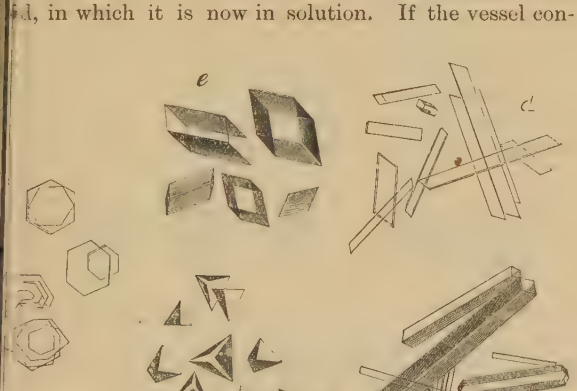


FIG. 32.—CRYSTALS OF HÆMOGLOBIN. (AFTER FUNKE.)
a, squirrel; *b*, guinea-pig; *c*, cat or dog; *d*, man; *e*, hamster.

ining the laky blood be allowed to stand on ice for some ours, a sediment usually forms at the bottom, and will e found in a successful experiment, when examined with he microscope, to consist chiefly of **blood-crystals.** he crystals differ in shape according to the animal from hose blood they were obtained; in man they have the

shape of prisms. The hæmoglobin of human blood crystallises with difficulty, but that of the guinea-pig, rat, or dog, much more readily.

3. The White Corpuscles.—The colourless corpuscles (Fig. 31, *a a*, *F.*) are larger than the red corpuscles, their average diameter being 10μ ($\frac{1}{2500}$ of an inch). They are further seen, at a glance, to differ from the red corpuscles by the irregularity of their form, and by their greater stickiness or adhesiveness, shown by their tendency to attach themselves to the glass slide, while the red corpuscles float about and tumble freely over one another.

A still more remarkable feature of the colourless corpuscles than the irregularity of their form is the unceasing variation of shape which they exhibit so long as

FIG. 33.—SUCCESSIVE FORMS ASSUMED BY COLOURLESS CORPUSCLES OF HUMAN BLOOD. (Magnified about 600 diameters.)

The intervals between the forms *a*, *b*, *c*, *d*, was a minute; between *d* and *e* two minutes; so that the whole series of changes from *a* to *e* took five minutes.

they are alive. The form of a red corpuscle is changed only by influences from without, such as pressure, or the like; that of the colourless corpuscle is undergoing constant alteration, as the result of changes taking place in its own substance. To see these changes well, a microscope with a magnifying power of five or six hundred diameters is requisite, and some arrangement for keeping the preparation gently warmed (to 40° C.), since heat makes the movements more active; and, even then, they are so gradual that the best way to ascertain their existence is to make a drawing of a given colourless corpuscle at intervals of a minute or two. This is what has been done with the corpuscle represented in Fig. 33, in which

epresents the form of the corpuscle when first observed ; its form a minute afterwards ; *c*, that at the end of the ond ; *d*, that at the end of the third ; and *e*, that at end of the fifth minute.

areful watching of a colourless corpuscle, in fact, ws that every part of its surface is constantly changing undergoing active contraction or being passively dilated the contraction of other parts. It exhibits **contractility** in its lowest and most primitive form.

While they are thus living and active, a complete owledge of the structure of the colourless corpuscles not be arrived at. Each corpuscle seems to be formed aply of a mass of the coarsely or finely granular bstance called **protoplasm** in which no distinction of

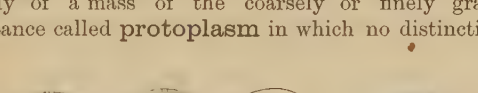


FIG. 34.—COLOURLESS CORPUSCLES OF BLOOD. (HARDY.)

A spherical and coarsely granular, the non-granular part being occupied by the nucleus ; B, spherical and finely granular ; C, showing nucleus after action of acetic acid ; D, flattened, as the corpuscle moves, and showing the nucleus.

rts can be seen (Fig. 34, A and B). This is especially the se when the corpuscle is at rest and assumes a spheroidal hape. Sometimes, however, the corpuscle, in the course f the movements just described, spreads itself out into a ery thin flat film (Fig. 34, D) ; and when that is the case here may be seen in its interior a rounded body, differing n appearance from the rest of the body of corpuscle. gain when a drop of blood is diluted with water, still etter with very dilute acetic acid, the spongy protoplasm f the white corpuscles swells up and becomes transparent, any of the granules becoming dissolved, and in this case he same rounded body becomes visible. This internal

rounded body, which differs in nature from the rest of the substance of the corpuscles, is called the **nucleus** (Fig. 34, C); and when the blood is treated under the microscope, with various staining fluids, such as solutions of carmine or logwood, the nucleus generally stains more deeply than the rest of the corpuscle.

The colourless corpuscle, with its nucleus, is what is called a **nucleated cell.** It will be observed that it lives in a free state in the plasma of the blood, and that it exhibits an independent contractility. In fact, except that it is dependent for the conditions of its existence upon the plasma, it might be compared to one of those simple organisms which are met with in stagnant water, and are called *Amœbæ*, whence the name 'amœboid' given to the movements of the colourless corpuscles of blood.

While the colourless corpuscles are thus nucleated cells, the red corpuscles have no such nucleus; and this is true not only of human blood but of the blood of all mammals, *i.e.* of all those animals which suckle their young; in all these the red corpuscle has no nucleus. In the case of birds, reptiles and fishes, however, the red corpuscles as well as the colourless are nucleated; and in the embryos [1] even of mammals the red corpuscles are at first nucleated.

We have seen that the colourless corpuscles consist of what may be spoken of as the cell-body, or contractile part, in which is imbedded a nucleus.

The body may sometimes be quite clear and transparent, though it more usually appears to be granular from the presence in it of minute particles which, varying in size, are spoken of as 'fine' or 'coarse.' We may regard these particles as simply imbedded in the ground-substance of which the cell-body is made up, and, since they are variable in size and numbers, as not essential to the structure of the corpuscle. What the real structure of the living, contractile ground-substance or protoplasm may be is still a matter of conjecture and dispute.

[1] An embryo is the rudimentary unborn young of any creature.

When the colourless corpuscles are examined chemically they are found to consist chiefly of water, and only 10–12 per cent. of solid matter. As in the case of the stroma of the red corpuscles, so here also this solid part is made up largely of **proteids** or substances closely allied to proteids. But frequently also some small amount of **fat** is found to be present, as also of a representative of that class of substances known as carbohydrates or starchy substances, called **glycogen**, which will be dealt with later on when treating of the liver. (See Lesson V.)

The parts played by the colourless corpuscles in the animal economy are probably varied and numerous, but our knowledge of them is very imperfect. We have seen (§ 82) that under special circumstances these corpuscles can, by means of their amœboid movements, migrate in large numbers through the walls of the blood-vessels into the tissues, and it is possible that here they may in some way assist in the removal of the causes which are giving rise to the disturbance. Quite probably a similar migration is taking place on a smaller scale at all times, for some as yet obscure but possibly similar purpose. Again, by their amœboid movements the colourless corpuscles can flow round small solid particles and absorb them into their cell-body; in other words they can feed on substances in the blood and thus be continually busied in keeping this fluid in a normal condition, more particularly when, as in disease, the composition of the blood is altered by the introduction of foreign matter such as bacteria, etc. Moreover it is extremely probable that the colourless corpuscles may act on the blood and on any foreign matter it may at times contain by means other than their amœboid movements; namely chemically by the discharge into the blood of substances formed within themselves. Finally there are reasons for supposing that when blood is shed, these corpuscles have something to do with starting that striking change, to which we have already alluded, known as the clotting or coagulation of blood.

4. Blood Platelets.—In addition to the red and white corpuscles, a third kind of rounded, colourless particles may, but with difficulty, be made out as existing in blood. These are known as "blood platelets." They are extremely minute, not much wider than the thickness of a red corpuscle, and usually disappear as soon as blood is removed from the body. But so little is known about them that we must not do more than simply draw attention to their existence.

5. The Origin and Fate of the Corpuscles.—The exact number of both red and colourless corpuscles present in the blood varies a good deal from time to time; and there is reason to think that both kinds of corpuscles are continually being destroyed or made use of. But since, on the whole, the average number of each kind of corpuscle is maintained during healthy life, it is evident that new corpuscles must be continually forming to take the place of those which have disappeared.

The colourless corpuscles are, as already described (p. 91), chiefly formed out of leucocytes which, originating in the lymphatic glands and other similar structures, are then passed along the lymphatic vessels into the blood.

Our knowledge of the origin of the red corpuscles is somewhat less definite; there is, however, no doubt that in the adult the chief seat of their formation lies in that marrow found in the cavities of bones which, from being very plentifully supplied with blood-vessels, is known as **red marrow**. There is some doubt as to whether the cells which give rise to red corpuscles in the marrow are similar to ordinary white corpuscles, or are a particular kind of cell; and the question has not as yet been definitely decided as to how the mammalian red corpuscle comes to have no nucleus, although formed in or from cells which are themselves nucleated.

Apart from what is known as to the disappearance of white corpuscles from the blood by migration through the

of the vessels, we cannot point with certainty to any fate which befalls them. There is no reason for supg that they are used up in giving rise to red corpuscles. hen we deal with the liver we shall see that the fluid which it forms or "secretes" is highly coloured, h not red. Observation and experiment both show he substance to which the colour of bile is due is bly derived from that coloured product of the mposition of hæmoglobin, known as hæmatin. If oglobin is thus the parent substance of the colouring er of the bile, then, since bile is formed by the liver day in large quantities, a correspondingly large daily ruction of red corpuscles must also be taking place.

The Physical Qualities of Blood.—The proverb "blood is thicker than water" is literally true, as blood is not only "thickened" by the corpuscles, hich it has been calculated that no fewer than 0,000,000 (eighty times the number of the human lation of the globe) are contained in a cubic inch, but ndered slightly viscid by the solid matters dissolved e plasma. The blood is thus rendered heavier than r, its specific gravity being about 1·055. In other ls, twenty cubic inches of blood have about the same ht as twenty-one cubic inches of water.

e corpuscles are heavier than the plasma, and their ne is usually somewhat less than that of the plasma. olourless corpuscles there are usually not more than e or four for every thousand of red corpuscles; but proportion varies very much, increasing shortly after is taken, and diminishing in the intervals between s. Average blood may be regarded as consisting of $\frac{2}{3}$ ma and $\frac{1}{3}$ corpuscles.

e blood is hot, its temperature being about 37° C. 6 F.).

The General Composition of Blood.—Considered ically, the blood is a faintly alkaline fluid, consisting ater, of solid and of gaseous matters.

The proportions of these several constituents vary according to age, sex, and condition, but the following statement holds good on the average :—

In every 100 parts of the blood there are 79 parts of water and 21 parts of dry solids ; in other words, the water and the solids of the blood stand to one another in about the same proportion as the nitrogen and the oxygen of the air. Roughly speaking, one quarter of the blood is dry, solid matter ; three quarters water. Of the 21 parts of dry solids, 12 ($=\frac{4}{7}$ths) belong to the corpuscles. The remaining 9 are about two-thirds (6·7 parts $=\frac{2}{7}$ths) proteids (substances like white of egg, coagulating by heat), and one-third ($=\frac{1}{7}$th of the whole solid matter) a mixture of saline, fatty, and carbohydrate matters and sundry products of the waste of the body, such as urea.

The total quantity of gaseous matter contained in the blood is equal to rather more than half the *volume* of the blood ; that is to say, 100 c.c. (or 100 cubic inches) of blood will contain about 60 c.c. (or 60 cubic inches) of gases. These gaseous matters are carbonic acid, oxygen and nitrogen ; or, in other words, the same gases as those which exist in the atmosphere, but in totally different proportions ; for whereas air contains nearly three-fourths nitrogen, one-fourth oxygen, and a mere trace of carbonic acid, the average composition of the blood gases is about two-thirds or more carbonic acid, and one-third or less oxygen, the quantity of nitrogen being exceedingly small, only 1–2 c.c. in 100 c.c. of blood.

It is important to observe that blood contains much more oxygen gas than could be held in solution by pure water at the same temperature and pressure. This power of holding oxygen depends upon the red corpuscles, the oxygen thus held by them being readily given up for purposes of oxidation. The connection between the oxygen and the red corpuscles is of a peculiar nature, being a sort of loose chemical combination with one of their constituents, and that constituent is, as we have said

ously, the hæmoglobin ; for solutions of hæmoglobin
e towards oxygen almost exactly as blood does.
arly the blood contains more carbonic acid than
be held in solution by pure water at the same tem-
ure and pressure. But unlike the oxygen, the
nic acid thus held by blood is not peculiarly associated
the hæmoglobin of the red corpuscles ; in fact it
s to be chiefly retained by some constituents of the
ma.

e corpuscles differ chemically from the plasma, in
ining a large proportion of the fats and phosphates,
e iron, and almost all the potassium, of the blood ;
the plasma, on the other hand, contains by far the
er part of the chlorine and the sodium.

e blood of adults contains a larger proportion of
constituents than that of children, and that of men
than that of women ; but the difference of sex is
ly at all exhibited by persons of flabby, or what is
d lymphatic, constitution.

imal diet tends to increase the quantity of the red
uscles ; a vegetable diet and abstinence to diminish
. Bleeding exercises the same influence in a still
marked degree, the quantity of red corpuscles being
nished thereby in a much greater proportion than
of the other solid constituents of the blood.

The Proteids of Plasma.—By cooling or the
ion of certain neutral salts the clotting of blood is
ded or even entirely prevented. The corpuscles may
be removed and the plasma obtained as a clear
ly yellow and slightly alkaline liquid composed of
t 90 per cent. water and 10 per cent. of solids in
ion. The solids consist chiefly of that kind of
rial which we have so frequently spoken of as proteids.
these proteids are typical of their class, and since
ids are without doubt the most important substances
with in the body, it will be as well to state at once
are the essential characteristics of a proteid.

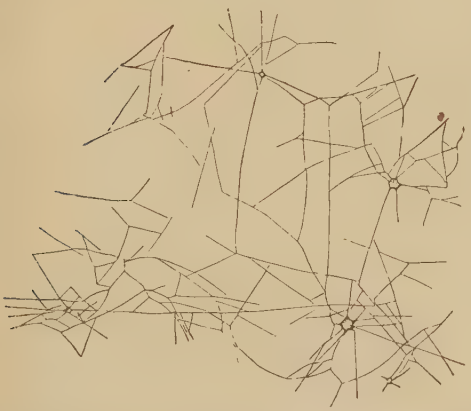
Proteids are, in the first place, extremely complex substances, so much so that chemists have not as yet been able to determine their constitution or assign any formula to them. Some are soluble in water, others only soluble in solutions of a neutral salt such as sodium chloride, while others are insoluble in either of the preceding solvents. When heated, with but few exceptions, they are altered or coagulated, as in the well-known change which the white of an egg, itself a typical proteid, undergoes when boiled.

In the next place proteids are composed of the four elements, carbon, hydrogen, oxygen and nitrogen, with frequently a small amount of sulphur; of these the nitrogen stands out as having a supreme importance. All the tissues of the body contain nitrogen and are continually undergoing a nitrogenous waste, and the body is quite unable to make use of nitrogen for the repair of this waste except it is presented in the form of a proteid. The general percentage composition of proteids is, roughly speaking, the same for all of them, and varies but slightly on either side of the following numbers:—carbon 53 parts, oxygen 22, hydrogen 7, nitrogen 16, and sulphur 1-2. In the absence of any formula this percentage composition becomes a most important characteristic.

All proteids give the three following reactions. (i) When boiled with nitric acid they turn yellow, and this yellow turns to orange on the addition of ammonia. (ii) Boiled with Million's reagent (a mixture of the nitrates of mercury) they give a pink colour. (iii) When mixed with caustic soda and a small amount of a solution of sulphate of copper they give a violet colour. These reactions suffice for the detection of any proteid in solution or as a solid.

The solids in the plasma of blood are chiefly proteids and are three in number. The first is known as **fibrinogen** and is precipitated by the addition to plasma of 15 per cent. of sodium chloride (ordinary salt). This

is readily attained by adding to the plasma an volume of a *saturated solution* of sodium chloride contains about 30 per cent. of salt. The fibrinogen ates out from solution as a fine, flocculent, viscid pitate. Fibrinogen is characterised by the fact it "sets" or coagulates when heated in solu- to 56° C. (132° F.). The second is called **para-ulin** and is similarly precipitated when the



5.—Network of Filaments left after washing away the ouring Matter from a thin, flat Clot of Blood. (Ranvier.)

a from which the fibrinogen has been removed is quently saturated by the addition of as much sodium de as it will dissolve. It coagulates when heated in on, at a temperature much higher than does ogen, namely 75° C. (167° F.). The third is known **rum-albumin**. It may, roughly speaking, be led as very like that kind of albumin with which one is familiar in the white of an egg, and while it

coagulates when heated to 75° C. (167° F.) as does paraglobulin, it differs from paraglobulin and also from fibrinogen by not being precipitated when its solution is saturated with sodium chloride.

The different precipitability of fibrinogen and paraglobulin in presence of varying amounts of sodium chloride or other "neutral" salt, such as the sulphates of sodium and magnesium, has been the starting point of all investigations on the processes concerned in the clotting of blood; we may therefore now proceed very appropriately to deal with the nature and causes of this striking phenomenon.

9. The Clotting of Blood.—If a drop of blood be spread out in a thin layer on a slide and kept from drying it soon becomes solid and gelatinous, as in the second experiment described on p. 94. When this solid is *carefully* washed, by streaming water over it very gently, the colouring matter is removed and a coarse network of extremely delicate fibres or filaments remains. (Fig. 35).

These filaments are formed in the blood and traversing it in all directions, uniting with one another and binding the corpuscles together, are the cause of the blood having become a semi-solid mass. The filaments are composed of a substance called **fibrin**; hence it is this formation of fibrin which is the cause of the solidification or clotting of the blood; but the phenomena of clotting, which are of very great importance, cannot be properly understood until the behaviour of the blood when drawn in much larger quantity than a drop has been studied.

When, by the ordinary process of opening a vein with a lancet, a quantity of blood is collected into a basin it is at first perfectly fluid: but in a very few minutes it becomes, through clotting, a jelly-like mass, so solid that the basin may be turned upside down without any of the blood being spilt. At first the clot is a uniform red jelly but very soon drops of a clear yellowish watery-looking

make their appearance on the surface of the clot, and
een it and the sides of the basin. These drops in-
e in number, and run together, and after a while it
ecome apparent that the originally uniform jelly has
ated into two very different constituents—the one a
yellowish liquid; the other a red, semi-solid, slightly
ken mass, which lies in the liquid. The liquid
s from the coloured mass because the latter shrinks
o squeezes it out.

e liquid is called the **serum**; the semi-solid mass
clot. Now the clot obviously contains the cor-
es of the blood, bound together by some other
ance; and this last, if a small part of the clot be
ined microscopically, will be found to be that
us-looking matter, **fibrin**, which has been seen form-
in the drop of blood. Thus the clot is made up
e corpuscles *plus* the fibrin of the plasma, while the
m is the plasma *minus* the fibrinous elements which
ntained.

e corpuscles of the blood are slightly heavier than
lasma, and therefore, when the blood is drawn, they
to sink very slowly towards the bottom, but as a
clotting is complete before the corpuscles have had
to sink appreciably. When, on the other hand, the
l clots slowly, the corpuscles have so much time to
that the upper stratum of plasma becomes quite free
red corpuscles before the fibrin forms in it; and,
equently, the uppermost layer of the clot is nearly
e: it then receives the name of the *buffy coat*. This
quently well seen in the blood of the horse, which often
slowly, and whose corpuscles are unusually heavy.
the blood is "whipped" with a bunch of twigs as soon
is drawn from the body, fibrin is formed as before,
n this case the clot is broken up as fast as it tends to
rmed. Under these circumstances the fibrin collects
the twigs, and a red fluid is left behind, consist-
f the serum *plus* the red corpuscles and many of the

colourless ones. The fibrin adhering to the twigs may readily be washed in a stream of water, and as thus obtained is a white, stringy, elastic and very insoluble substance. It gives, when tested, all the reactions characteristic of proteids, and is in fact itself a proteid, although somewhat impure.

The clotting of the blood is hastened, retarded, or temporarily prevented by many circumstances.

(*a*) *Temperature.*—A temperature up to or slightly above 40° C. (104° F.) accelerates the clotting of the blood; a low one retards it very greatly; so much so that blood kept at a temperature close to freezing point may remain fluid for a very long time indeed.

(*b*) *The addition of neutral salts to the blood.*—Many salts, and more especially sulphate of sodium or magnesium and sodium chloride (common salt), dissolved in the blood in sufficient quantity, prevent its clotting; but clotting sets in when water is added, so as to dilute the saline mixture.

(*c*) *Contact with living or not living matter.*—Contact with not living matter promotes the clotting of the blood. Thus, blood drawn into a basin begins to clot first where it is in contact with the sides of the basin; and a wire introduced into a living vein will become coated with fibrin, although perfectly fluid blood surrounds it.

On the other hand, direct contact with living matter retards, or altogether prevents, the clotting of the blood. Thus, blood remains fluid for a very long time in a portion of a vein which is tied at each end. The heart of a turtle remains alive for a lengthened period (many hours or even days) after it is extracted from the body; and, so long as it remains alive, the blood contained in it will not clot, though, if a portion of the same blood be removed from the heart, it will clot in a few minutes. Blood taken from the body of the turtle, and kept from clotting by cold for some time, may be poured into

separated, but still living, heart, and then will clot.

reshly deposited fibrin acts somewhat like living er, coagulable blood remaining fluid for a long time ubes coated with such fibrin.

he clotting of blood being thus due to the appearance of fibrin we may now consider how and why it is ned when blood is shed.

he clotting of the blood is an altogether physico-nical process, dependent upon the properties of ain of the constituents of the plasma. This is proved he fact that if common table salt be gradually added lood plasma which has been kept from clotting by l, or by the action of neutral salts, a white, floc-nt, somewhat viscid substance is thrown down or cipitated as soon as sufficient salt has been added. substance so thrown down is known by the name **plasmine** and may be separated by filtration, and ified by washing with a concentrated solution salt, in which it is insoluble. It is not fibrin, for reas fibrin is characteristically insoluble, this stance is readily soluble in distilled water, giving a r limpid solution. But this solution does not long ain so ; unless special precautions, such as exposing old, &c., be taken, it soon becomes viscid, then turns a jelly, and at last forms an unmistakable clot of e fibrin. The substance in question is therefore an ecedent of fibrin, which, by some changes or other, is verted into fibrin ; that is to say, the clotting of blood due to the conversion of this soluble antecedent of in into insoluble fibrin.

he exact nature of the changes involved in this con-sion have not even yet been thoroughly worked out ; the following facts throw a good deal of light on m :—The pericardium and other serous cavities in the y, contain a clear fluid, which may be briefly described consisting of the elements of the blood without the

red blood-corpuscles. This fluid sometimes clots spontaneously, as the blood plasma would do, but very often shows no disposition to clot spontaneously, especially if it is not removed from the body until some hours after death. When the latter is the case, the fluid may nevertheless be made to clot and yield true fibrin, by adding to it a few drops of whipped blood, *i.e.* of blood which has clotted, or a little serum of blood. Now if a specimen of pericardial fluid, which has been thus observed not to clot spontaneously, but to clot readily on the addition of blood or serum, be treated with salt in the same way as described above for blood plasma, a substance will be thrown down, which, at first sight, looks exactly like that thrown down from blood plasma. But there is a great difference, for the substance thus obtained from pericardial fluid when dissolved in water will not clot spontaneously, though its solutions may be made to clot at any time by the addition of a little serum, or whipped blood. It, too, may therefore be spoken of as an antecedent of fibrin, and indeed it was on this account that it first received the name of **fibrinogen**, or "fibrin maker," having been obtained from serous fluids before it was shown to be present in plasma. It is undoubtedly present in the substance thrown down by salt from blood plasma, but then it is mixed with other bodies ; and the presence of some or other of these bodies seems to be the reason why in this case it is converted into fibrin, and so gives a clot. Conversely the absence of this body or these bodies from pericardial fluid is the reason why pericardial fluid or fibrinogen prepared from pericardial fluid, does not clot spontaneously.

We have previously described how this fibrinogen may be separated from plasma. If, now, the yellow fluid or serum which exudes from a blood-clot be treated with salt in a similar way (see p. 109) no fibrinogen can ever be obtained from it, while on the other hand it is found to contain both paraglobulin and serum albumin.

comparison of plasma and serum thus shows that during clotting, *i.e.* during the formation of fibrin, one constituent of the plasma, namely, fibrinogen, disappears, the other two proteids being left to appear in the serum.

Putting these facts together there can be no doubt that when blood clots the fibrin is formed out of fibrinogen. But there must also be some substance in blood after it is shed which leads to the conversion of fibrinogen into fibrin; for pericardial and other serous fluids contain fibrinogen, but do not usually clot, and purified solutions of fibrinogen never clot spontaneously. What is this substance?

If serum be precipitated with an excess of strong alcohol and after some weeks the precipitate is collected and extracted with distilled water, this watery extract contains very little solid matter, but is found to be active in causing the conversion of fibrinogen into fibrin. We do not as yet know exactly what the substance is in this extract which brings about the change of the fibrinogen, but for reasons into which we cannot now enter, it is classed with the "ferments," of which we shall have to speak when we come to consider digestion. These ferments are characterized by their power, even when present in small quantities, of producing great changes in other bodies without themselves entering into the changes. Thus the particular ferment of which we are speaking, and which has been called "**fibrin ferment**," or "**thrombin**," produces fibrin, and yet does not itself become part of the fibrin so produced.

This ferment is apparently not present in healthy blood as it circulates in the living blood-vessels, but makes its appearance when the blood is shed. We do not know exactly from what source it comes, but there are reasons for thinking that it arises from a breaking down of some kind of white corpuscle, or it may be of the blood-platelets.

Finally, then, we may say that *fibrin as such does not*

exist in the blood at the moment of its being shed, but makes its appearance afterwards on account of the action of fibrin ferment on fibrinogen, other bodies as well being possibly concerned in the matter.

10. The Quantity and Distribution of Blood in the Body.—The total quantity of blood contained in the body varies at different times, and the precise ascertainment of its amount is very difficult. It may probably be estimated, on the average, at not less than one-thirteenth or about 7 per cent. of the weight of the body.

Its distribution may be stated in round numbers as follows :—

One quarter, in the heart, lungs and large blood-vessels.

One quarter, in the liver.

One quarter, in the skeletal muscles.

One quarter, in the other organs of the body.

11. The Functions of the Blood.—The function of the blood is to supply nourishment to, and take away waste matters from, all parts of the body. All the various tissues may be said to live on the blood. From it they obtain all the matters they need, and to it they return all the waste material for which they have no longer any use. It is absolutely essential to the life of every part of the body that it should be in such relation with a current of blood, that matters can pass freely from the blood to it, and from it to the blood, by transudation through the walls of the vessels in which the blood is contained. And this vivifying influence depends upon the corpuscles of the blood. The proof of these statements lies in the following experiments :—If the vessels of a limb of a living animal be tied in such a manner as to cut off the supply of blood from the limb, without affecting it in any other way, all the symptoms of death will set in. The limb will grow pale and cold, it will lose its sensibility, and volition will no longer have power over it ; it will stiffen, and eventually mortify and decompose.

But, if the ligatures be removed before the death iffening has become thoroughly established and the ood be allowed to flow into the limb, the stiffening eedily ceases, the temperature of the part rises, the nsibility of the skin returns, the will regains power over muscles, and, in short, the part returns to its normal ndition.

If, instead of simply allowing the blood of the animal erated upon to flow again, such blood, deprived of its rin by whipping, but containing its corpuscles, be artiially passed through the vessels, it will be found nearly effectual a restorative as entire blood ; while, on the her hand, the serum (which is equivalent to whipped ood without its corpuscles) has no such effect.

It is not necessary that the blood thus artificially inected should be that of the subject of the experiment. en, or dogs, bled to apparent death, may be at once and fectually revived by filling their veins with blood taken om another man, or dog ; an operation which is known y the name of *transfusion*.

Nor is it absolutely necessary for the success of this eration that the blood used in transfusion should belong an animal of the same species. The blood of a horse ill permanently revive an ass, and, speaking generally, e blood of one animal may be replaced without injurious fects by that of another closely-allied species ; while hat of a very different animal will be more or less inurious, and may even cause immediate death.

12. Lymph: its Character and Composition.—ymph, as previously explained, is the fluid which fills he lymphatic vessels, and at the place where it is first rmed is a mere overflow of fluid from the blood through he walls of the capillaries. This exudation of fluid may lso be accompanied by a migration of some of the olourless corpuscles of the blood. Hence it is at once vident that lymph may, broadly speaking, be regarded s so much blood *minus* its red corpuscles.

Lymph is most easily and plentifully obtained for examination from the thoracic duct. As procured from this vessel it has the advantage of being representative of an average specimen of lymph, since it is a mixture of fluid collected from nearly all parts of the body. But the precaution must be taken to collect the lymph from a fasting animal in order to avoid the complication due to admixture of the lymph from the body generally with certain special substances which are taken up by the lymphatics of the intestine after a meal. After a meal, the lymph from the alimentary canal differs strikingly, in one respect, as we shall see later on, from that which comes from it in the absence of food. Taking lymph, then, from the thoracic duct of a fasting animal, in which, however, the lymph from the intestine still joins the lymph formed in the rest of the body, it is found to be a transparent, faintly yellow fluid. When examined under the microscope it is seen to contain a number[1] of corpuscles, the **lymph-corpuscles** or **leucocytes**, very similar to the colourless corpuscles of blood, though perhaps on the whole rather smaller, and like the latter showing amœboid movements, especially if kept warm. These leucocytes may represent some of the white blood-corpuscles which migrated from the vessels, but by far the larger number are formed in the lymphatic glands (see p. 91).

When examined chemically lymph is found to contain the same salts as are present in plasma and in about the same amount: the total solids are, however, considerably less than in plasma,[2] and this is due to a deficiency of proteids. But the proteids present in lymph are the same in kind as the three already described as found in plasma, viz., fibrinogen, paraglobulin and serum albumin.

[1] Equal on the average to the number present in blood, so that in a drop of lymph very few would be seen and often none at all.

[2] Only about 5 per cent. of its weight as compared with 8 to 10 per cent. in plasma.

ce lymph clots when left to itself and yields fibrin tical with that obtained from blood, only in smaller ntities so that the clot is less firm than from blood. e gas may also be extracted from it, but in the absence ed corpuscles the amount of oxygen it yields is scarcely reciable; the bulk of the gas is carbonic acid and a small amount of nitrogen.

verage lymph is therefore very similar to plasma ewhat diluted with water; but it is important to ce from what has been said above that the dilution s not affect the salts and the proteids to the same nt. Neither is the dilution the same in lymph col- ed from different regions of the body. Thus lymph n the arm or leg contains less, and lymph from the r more solid matter than is present in average mixed ph from the thoracic duct. The significance of se facts will become apparent when we speak of the bable mode of formation of lymph. While lymph thus fers in composition when derived from various parts of body, it also differs when collected from the same part different times. Usually the difference is slight, but in case of one source it is marked and important. In a ting animal the lymph coming from the intestines is entially the same as average lymph: but after food s been taken, and especially if the food contains ch fat, and food always contains some fat, this lymph pears to be quite white or "milky." Owing to the inness of the walls of the lymphatics the contents e visible from their exterior, so that the vessels also pear white or milky, and hence this particular set of mphatics is known as the **lacteals**, and the contents called **chyle**. The only difference between chyle and lymph ordinarily present in the lacteals is that chyle lds in suspension a large amount of fat (from 5 to 15 r cent.) in a state of extremely fine division. These nute particles of fat reflect a great deal of the light fall- upon them and hence the fluid appears white. Some

of the fat in chyle exists in the form of minute globules, similar to those present in milk, but the larger part is so finely divided that it can only be spoken of as "granules" and in this form is known as the *molecular basis* of chyle.

13. The Mode of Formation of Lymph.—In all which we have so far said respecting lymph we have spoken of it merely as an exudation of fluid from the walls of the capillaries. The word "exudation" was used purposely, as not implying more than that some of the liquid part of the blood passes out into the tissues, and certainly as not expressing any view as to the nature of the processes concerned in that passage. But now that we have dealt with the composition of lymph, and especially since we have seen that the composition varies according to the part of the body from which it flows, we may profitably consider what are the causes which in the first place lead to the presence of lymph in the lymph spaces of the tissues.

Two processes suggest themselves at once as possible causes; these are **filtration** and **diffusion**. With the first of these every one is more or less familiar, and we need say no more than that it consists in the passage of fluid and of substances in solution through a porous membrane as the result of a difference of pressure on the two sides of the membrane. Diffusion, on the other hand, is, broadly speaking, independent of the difference of pressure necessary to cause filtration. A simple experiment shows at once the essential feature of diffusion. Tie a piece of parchment paper tightly over the wide end of an ordinary "thistle tube" as used by chemists. Then fill the bulb and about one inch of the tube with a strong (20 per cent.) solution of sugar or common table-salt and fix the tube vertically, as in Fig. 36, in a beaker of water, so that the surface of the solution in the tube is *at the same level* as that of the water in the beaker. In a short time the sugar or salt begins to pass out through the paper and may be detected in the water in the beaker. At the same time

passes through the paper in the opposite direction
he tube and in considerable quantity, so that the
rises in the narrow part of the tube and may ulti-
y stand several inches above the surface of that
is in the beaker.

stituting the wall of the capillaries for the paper used
preceding experiment we have the conditions
sary for a possibly diffusive
hange between the blood on
ne side of that wall and the
in the tissues on the other.
here we may say at once that
sion will not account to any
ed extent for the formation of
h. In support of this state-
it may suffice to point out
lymph contains a considerable
nt of proteids, and these are
cteristically non-diffusible.[1]
the other hand the blood-
ure in the capillaries, though
less than in the arteries, is not
siderable, and is exerted
st the walls of these vessels.
we then account for the for-
on of lymph as the result of
tion? Here again we may at
say that the passage of fluid
gh the walls of the capillaries
r the influence of pressure has
at deal to do with the formation of lymph. We
justified in this view by the fact that, as a
al rule, increase of blood-pressure in the capillaries
to an increased flow of lymph from the parts

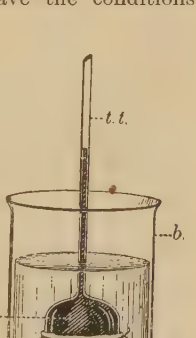


FIG. 36.—TO ILLUSTRATE A SIMPLE EXPERIMENT ON DIFFUSION.

t.t. thistle tube; *p.p.* parchment paper; *s.* sugar or salt solution; *b.* beaker; *w.* water in beaker.

bstances such as the proteids of blood, also gelatin, which will not
, are known as *colloids*, in contradistinction to crystalline sub-
s or *crystalloids*, which diffuse readily.

they supply. But we must not conclude therefore that the process is entirely due to filtration. Experiments may be made in which while we know that the blood-pressure in the capillaries is much greater than usual, no increased formation of lymph takes place. Again, it is possible by certain means to obtain a greatly increased flow of lymph from parts in whose capillaries there is no obvious increase of blood-pressure. Neither of these results would hold good in the case of any ordinary filter. But in the case of lymph, as a matter of fact, it is *not an ordinary filter* which we have to deal with. The wall of a capillary is made of cells which are *alive* and are thus *able to change their condition from time to time*. By this means the capillary wall is, as it were, the master of the current of fluid passing across it under varying filtrational pressure, and can determine not only how much fluid shall pass, but in what relative proportions its several constituents shall make their exit. When once this idea is clearly grasped many difficulties disappear. We can understand more easily why the lymph differs in composition as formed in various parts of the body. We see why arterial dilation is less potent to increase lymph formation than is venous obstruction, for although they both increase the blood-pressure in the capillaries, venous obstruction is necessarily accompanied by a stagnation of blood which presumably alters the condition of the capillary wall. We can also now more easily appreciate many details of inflammation as previously described (p. 82).

The formation of lymph may thus be regarded as the result of the passage under pressure of certain constituents of the blood-plasma through the walls of the capillaries, the passage being made *peculiar and unlike an ordinary filtration by the influence of the living walls of the vessels through which it is taking place*.

LESSON IV

RESPIRATION

he Gases of Arterial and Venous Blood.—The the general nature and properties of which have escribed in the preceding Lesson, is the highly x product, not of any one organ or constituent body, but of all. Many of its features are doubt- ven to it by its intrinsic and proper structural ts, the corpuscles; but the general character of od is also profoundly affected by the circumstance ery other part of the body takes something from od and pours something into it. The blood may pared to a river, the nature of the contents of is largely determined by that of the head waters, that of the animals which swim in it; but which very much affected by the soil over which it by the water-weeds which cover its banks, and ients from distant regions; by irrigation works re supplied from it, and by drain-pipes which flow

of the most remarkable and important of the effected in the blood is that which results, in rts of the body, from its simply passing through ies, or, in other words, through vessels the walls h are thin enough to permit a free exchange the blood and the fluids which permeate the t tissues (Lesson II.).

if blood be taken from the artery which supplies

a limb, it will be found to have a bright scarlet colour while blood drawn, at the same time, from the vein of th limb, will be of a dark purplish hue. And as this con trast is met with in the contents of the arteries and veins i general (except the pulmonary artery and veins), th scarlet blood is commonly known as **arterial** and th dark blood as **venous.**

This conversion of arterial into venous blood take place in most parts of the body, while life persists. Thus if a limb be cut off and scarlet blood be forced into it arteries by a syringe, it will issue from the veins as dar blood.

When specimens of venous and of arterial blood ar subjected to chemical examination, the differences pre sented by their solid and fluid constituents are found t be very small and inconstant. But the gaseous content of the two kinds of blood differ widely in the proportio which the carbonic acid gas bears to the oxygen ; ther being a smaller quantity of oxygen and a greater quantit of carbonic acid, in venous than in arterial blood.

Every 100 volumes of blood contain about 60 volume of gases. These may be extracted by placing the bloo in a vessel connected with the vacuum of a mercuri pump. The reduction of pressure on the surface of th blood leads to a rapid exit of the gases into the vacuum they can now be collected and measured and their respe tive volumes determined. The composition of the bloo gases is thus found to be the following :—

	Arterial Blood.	Venous Blood.
Oxygen	20 vols.	8–12 vols.
Carbonic acid ...	40 ,, ...	46 ,,
Nitrogen	1–2 ,, ...	1–2 ,,

This difference in their gaseous contents is the on essential difference between venous and arterial blood, may be demonstrated experimentally. For if veno blood be shaken up with oxygen, or even with air,

xygen, loses carbonic acid, and takes on the colour operties of arterial blood. Similarly, if arterial e treated with carbonic acid so as to be thoroughly ed with that gas, it gains carbonic acid, loses . and acquires the true properties of venous blood ; for a reason to be mentioned below, the change take place so readily nor is it so complete in this in the former. The same result is attained, though owly, if the blood, in either case, be received into er, and then placed in the oxygen, or carbonic acid ; n moist animal membrane allowing the change to ted with perfect ease, and offering no serious im- nt to the passage of either gas.

ous blood is characterized not only by the large i of carbonic acid which it contains, but also by the at the red corpuscles have given up a good deal of oxygen for the purposes of oxidation, or, as the sts would say, have become reduced. This is the why arterial blood is not so easily converted into blood by exposure to carbonic acid as is venous into arterial by exposure to oxygen. There is, in mer case, a want of some oxidizable substance to off the oxygen from and so to reduce the red cor- s. When such an oxidizable substance is added (as, stance, either ammonium sulphide or Stokes' re-) the blood at once and immediately becomes com- venous.

tically we may say that the most important differ- between venous and arterial blood is not so much lative quantities of carbonic acid as that the red cles of venous blood have lost a good deal of oxygen, duced, and ready at once to take up any oxygen to them.

ilarly the loss of oxygen by the red corpuscles is ief reason why the scarlet arterial blood turns

is made by mixing some tartaric acid with a solution of ferrous and then adding ammonia until the mixture is alkaline.

of a more purple or claret colour in becoming venous. It has indeed been urged that the red corpuscles are rendered somewhat flatter by oxygen gas, while they are distended by the action of carbonic acid (Lesson III., p. 98). Under the former circumstances they may, not improbably, reflect the light more strongly, so as to give a more distinct colouration to the blood ; while, under the latter they may reflect less light, and, in that way, allow the blood to appear darker and duller.

This, however, can only be a small part of the whole matter ; for solutions of hæmoglobin or of blood-crystals (Lesson III.), even when perfectly free from actual blood corpuscles, change in colour from scarlet to purple, according as they gain or lose oxygen. It has already been stated (p. 98), that oxygen most probably exists in the blood in loose combination with hæmoglobin. And further, a solution of hæmoglobin, when thus loosely combined with oxygen, has a scarlet colour, while a solution of hæmoglobin deprived of oxygen has a purplish hue. Hence arterial blood, in which the hæmoglobin is richly provided with oxygen, is naturally scarlet, while venous blood, which not only contains an excess of carbonic acid, but whose hæmoglobin also has lost a great deal of its oxygen, is purple.

The conditions under which the gases exist in blood are peculiar and important in connection with a point which we shall have to discuss later on, namely *how* venous blood becomes arterial in the lungs and *how* arterial blood becomes venous in the tissues. As to the nitrogen, we may say at once that it is apparently in a state of simple solution, as though the blood were so much water. A very small part of the oxygen is similarly simply dissolved in the blood, but practically almost the whole of it is *in a state of loose chemical combination with the hæmoglobin of the red corpuscles.* The facts which prove this are simple and conclusive. In the absence of red corpuscles plasma and serum only absorb as much oxygen as does an equal

ty of water, namely about one volume per cent. ; od, where the red corpuscles are present, may con- much as 20 volumes per cent. of oxygen. Again, us of hæmoglobin absorb oxygen as readily and as blood does. Finally, the oxygen is known to ly combined with the hæmoglobin, because when subjected to a gradually increasing vacuum, the does not come off uniformly and progressively, vacuum is made greater, in the way it would if e in mere solution ; on the contrary it *escapes sudden rush after the pressure has been considerably d.*

conditions under which carbonic acid exists in the may also be shown to be those of a loose chemical nation ; but beyond this fact our knowledge is hat incomplete. It is known, however, that the nic acid is combined chiefly in some constituents of lasma and not with the corpuscles, and most rities consider that the larger part is present in a united with sodium in the form of sodium bicar- e, $NaHCO_3$.

The Nature and Essence of Respiration.—All the s, as we have seen, are continually using up oxygen. life in fact is dependent on a continual succession dations. Hence they are greedy of oxygen, while at me time they are continually producing carbonic and other waste products). The demand for oxygen et by a supply from the red corpuscles, and the n they give up passes through the walls of the aries, across the lymph and so to the cells of which ssue is composed. At the same time the carbonic passes across the lymph in the opposite direction, gh the capillary walls and into the blood, by which it nce whirled away into the veins. The blood there- leaves the tissue poorer in oxygen and richer in nic acid than when it came to it ; and this change is hange from the arterial to the venous condition.

This gaseous interchange between the blood and the tissues is frequently spoken of as the **respiration of the tissues** or **internal respiration.**

On the other hand, if we seek for the explanation of the conversion of the dark blood in the veins into the scarlet blood of the arteries, we find, 1st, that the blood remains dark in the right auricle, the right ventricle, and the pulmonary artery ; 2nd, that it is scarlet not only in the aorta, but in the left ventricle, the left auricle, and the pulmonary veins.

Obviously, then, the change from venous to arterial takes place in the capillaries of the lungs, for these are the sole channels of communication between the pulmonary arteries and the pulmonary veins.

But what are the physical conditions to which the blood is exposed in the pulmonary capillaries ?

These vessels are very wide, thin walled, and closely set, so as to form a network with very small meshes, which is contained in the substance of an extremely thin membrane. This membrane is in contact with the air, so that the blood in each capillary of the lung is separated from the air by only a delicate pellicle formed by its own wall and the lung membrane. Hence an exchange very readily takes place between the blood and the air ; the latter gaining moisture and carbonic acid, and losing oxygen.[1]

This is the essential step in respiration. That it really takes place may be demonstrated very readily, by the experiment described in the first Lesson (p. 5), in which air expired was proved to differ from air inspired, by containing more heat, more water, more carbonic acid, and less oxygen ; or, on the other hand, by putting a ligature

[1] The student must guard himself against the idea that arterial blood contains no carbonic acid, and venous blood no oxygen. In passing through the lungs venous blood loses only a part of its carbonic acid and arterial blood, in passing through the tissues, loses only a part of its oxygen. In blood, however venous, there is in health always some oxygen ; and in even the brightest arterial blood there is actually about twice as much carbonic acid as there is of oxygen. See the table on p. 124.

he windpipe of a living animal so as to prevent air passing into, or out of, the lungs, and then examin- the contents of the heart and great vessels. The on both sides of the heart, and in the pulmonary and aorta, will then be found to be as completely us as in the venæ cavæ and pulmonary artery.

though the passage of carbonic acid (and hot y vapour) out of the blood and of oxygen into it e essence of the respiratory process—and thus a brane with blood on one side, and air on the other, that is absolutely necessary to effect the purification e blood—yet the accumulation of carbonic acid is so , and the need for oxygen so incessant, in all parts he human body, that the former could not be cleared , nor the latter supplied, with adequate rapidity, out the aid of extensive and complicated accessory linery—the arrangement and working of which must be carefully studied.

The Organs of Respiration.—The back of the th or **pharynx** communicates by two channels with external air (see Fig. 37, *g.f.e.*). One of these is ed by the nasal passages, which cannot be closed by muscular apparatus of their own; the other is ented by the mouth, which can be shut or opened at

mediately behind the tongue, at the lower and front of the pharynx, is an aperture—the **glottis** (Fig. *Gl*)—capable of being closed by a sort of lid—the **glottis** (Fig. 37, *e.*)—or by the shutting together of ide boundaries, formed by the so-called **vocal cords.** glottis opens into a chamber with cartilaginous walls e **larynx**; and leading from the larynx downwards g the front part of the throat, where it may be very ily felt, is the **trachea,** or windpipe (Fig. 37, *c*, Fig. *Tr.*).

the trachea be handled through the skin, it will be d to be firm and resisting. Its walls are, in fact,

strengthened by a series of cartilaginous hoops, which hoops are incomplete behind, their ends being united

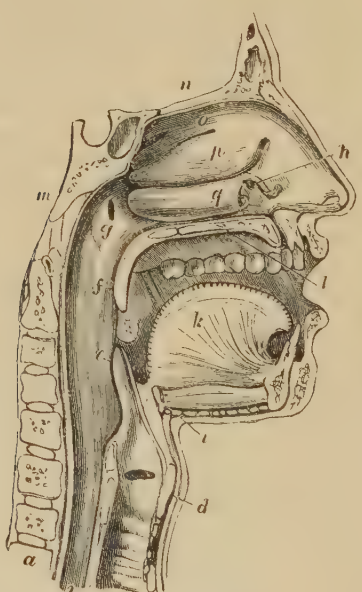
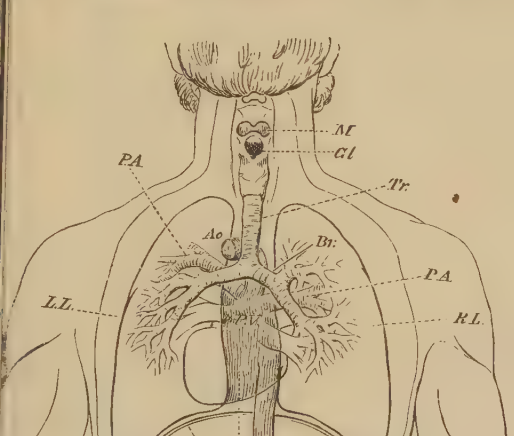


FIG. 37.—A SECTION OF THE MOUTH AND NOSE TAKEN VERTICALLY, A LITTLE TO THE LEFT OF THE MIDDLE LINE.

a, the vertebral column; *b*, the gullet; *c*, the wind-pipe; *d*, th thyroid cartilage of the larynx; *e*, the epiglottis; *f*, the uvula; *g*, th opening of the left Eustachian tube; *h*, the opening of the left lachrym duct; *i*, the hyoid bone; *k*, the tongue; *l*, the hard palate; *m*, *n*, th base of the skull; *o*, *p*, *q*, the superior, middle, and inferior turbin bones. The letters *g*, *f*, *e*, are placed in the pharynx.

only by muscle and membrane, where the trachea come into contact with the *œsophagus*, or gullet. The trache passes into the thorax, and there divides into two branches

ht and a left, which are termed the **bronchi** (Fig. r.). Each bronchus enters the lung of its own side, then breaks up into a great number of smaller hes, which are called the **bronchioles** or **bron-l tubes**. As these diminish in size, the cartilages, are continued all through the bronchi and their



8.—Back View of the Neck and Thorax of a Human Subject om which the Vertebral Column and whole Posterior Wall the Chest are supposed to be removed.

nouth ; *Gl.* glottis ; *Tr.* trachea ; *L.L.* left lung ; *R.L.* right lung ; onchus ; *P.A.* pulmonary artery ; *P.V.* pulmonary veins ; *Ao.* aorta ; phragm ; *H.* heart ; *V.C.I.* vena cava inferior.

ramifications, become smaller and more scattered eventually disappear, so that the walls of the smallest chial tubes are entirely muscular or membranous. while the trachea and bronchi are kept permanently and pervious to air by their cartilages, the smaller

bronchial tubes may be almost closed by the contraction of their muscular walls.

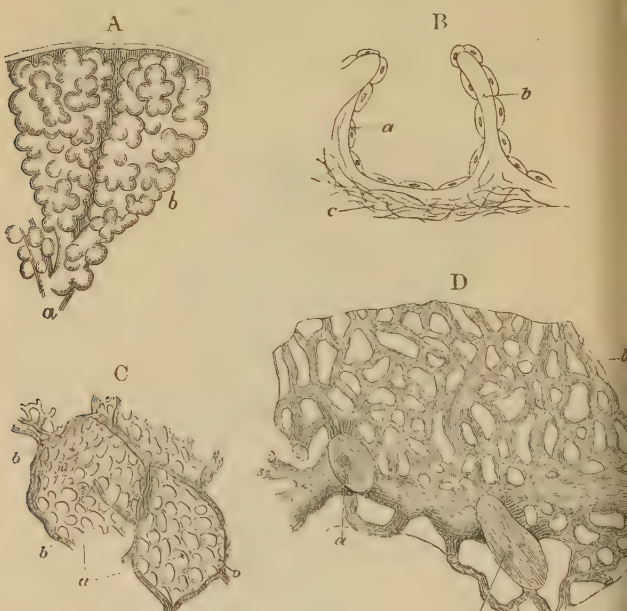


FIG. 39.

A. Two infundibula (*b*) with the ultimate bronchial tube (*a*) which opens into them. (Magnified 20 diameters.)

B. Diagrammatic view of an air-cell of A seen in action; *a*, epithelium; *b*, partition between two adjacent cells, in the thickness of which the capillaries run; *c*, fibres of elastic tissue.

C. Portion of injected lung magnified: *a*, the capillaries spread over the walls of two adjacent air-cells; *b*, small branches of arteries and veins.

D. Portion still more highly magnified.

Each finer bronchiole ends at length in an elongated dilatation about $\frac{1}{30}$ of an inch in diameter on the average and known as an **infundibulum** (Fig. 39, A. b). The wa

n infundibulum sends flattened projections into its
or and thus forms a series of thin partitions by
the cavity of the infundibulum is divided up into a
number of little sacs or chambers. These sacs are
lveoli or **air-cells.**

very thin walls (Fig. 39, B *b*) which separate these
i are supported by much delicate and *highly elastic*
and carry the wide and close-set capillaries into
the ultimate ramifications of the pulmonary artery
its blood (Fig. 39, C, D). Thus, the blood contained
ese capillaries is exposed on both sides to the air—
separated from the alveolus on either hand only by
very delicate pellicle which forms the wall of the
lary, and the lining of the alveolus. The partitions
een the alveoli are covered with extremely thin
ned cells, which may be easily seen in the lung of a
g animal but are reduced to almost nothing in the
of an adult.

e infundibula are bound together in groups by con-
ve tissue to form larger masses termed **lobules.**
e lobules are similarly bound together in groups to
lobes and the several lobes are united to form a
. The blood-vessels, nerves and lymphatics of each
are carried by the connective tissue which binds the
e together.

e trachea is essentially a tube whose wall is strength-
and whose bore is kept open by C-shaped hoops or
s of cartilage. These hoops lie imbedded in fibrous
ective tissue in the outer part of the wall, in which
there is a certain amount of unstriated muscular
e, running chiefly across the space between the ends
ch cartilaginous hoop. The inner surface of the tube
ed with a **mucous membrane.**[1] This consists of

[1] This name is applied generally to the membranes lining those in-
l passages of the body which communicate with its surface, such
e respiratory passages, the alimentary canal, and the bladder.
us membranes become continuous with the skin at the edge of the
ing on the surface. They derive their name from the fact that they

an epithelium of **ciliated cells**, interspersed with **mucous cells** ; these lie on a distinct basement membrane and below this is a small amount of lymphoid and elastic tissue. (See Lesson XII.) Between the mucous membrane and the outer layer which carries the hoops of cartilage, there is a certain amount of areolar connective

FIG. 40.—CILIATED EPITHELIUM CELLS FROM THE TRACHEA OF THE RABBIT, HIGHLY MAGNIFIED. (SCHÄFER.)

m^1, m^2, m^3, mucus-secreting cells lying between the ciliated cells and seen in various stages of mucin-formation.

tissue (p. 86), in which some small mucous glands are imbedded ; this constitutes the submucous layer. The ciliated cells are elongated columnar cells with a large and distinct nucleus. During life the cilia vibrate incessantly backwards and forwards, but work on the whole in such a way as to sweep both liquid (mucus) and solid particles outwards or towards the mouth. (See also Lesson VII. The mucous and ciliated cells extend from the trachea into the smallest branches of the bronchi.

are covered with a viscid secretion called **mucus**, whose characteristic constituent, **mucin**, is secreted by special mucous cells or by small mucous glands, imbedded in or lying beneath the membrane.

conditions could be more favourable to a ready nge between the gaseous contents of the blood and of the air in the alveoli than the arrangements obtain in the pulmonary capillaries; and, thus far, ructure of the lung fully enables us to understand is that the large quantity of blood poured through lmonary circulation becomes exposed in very thin s, over a large surface, to the air. But the only of this arrangement would be, that the pulmonary ould very speedily lose all its oxygen, and become letely saturated with carbonic acid, if special pro- were not made for its being incessantly renewed. renewal is brought about by the working of certain ural and mechanical arrangements which must now scribed in detail.

The Thorax and Lungs.—The lungs (and heart) nclosed in what is practically an air-tight box, whose are movable. This box is the thorax. In shape it nical, with the small end turned upwards, the back e box being formed by the spinal column, the sides e ribs, the front by the sternum or breast-bone, the m by the diaphragm, and the top by the root of the (Fig. 38).

e two lungs occupy almost all the cavity of this box h is not taken up by the heart (Fig. 41). Each nclosed in its serous membrane, the **pleura**, ible bag (very similar to the pericardium, the chief rence being that the outer bag of each pleura is, over greater part of its extent, quite firmly adherent to walls of the chest and the diaphragm, while the outer of the pericardium is for the most part loose), the r bag closely covering the lung and the outer forming ing to the cavity of the chest[1] (Fig. 42, pl.). So long e walls of the thorax are entire, the cavity of each

[1] ere is a small amount of fluid between the two surfaces of the , to facilitate their rubbing easily against one another. This us" fluid is in reality, as is pericardial fluid, a form of lymph.

pleura is practically obliterated, that layer of the pleura which covers the lung being in close contact with that which lines the wall of the chest ; but if a small opening

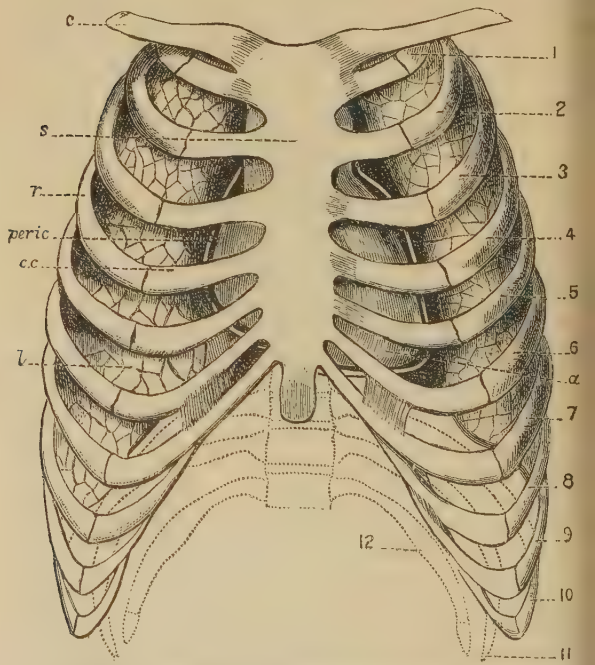
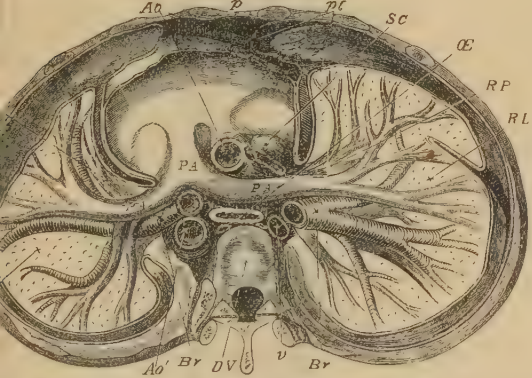


FIG. 41.—DIAGRAM OF THE THORAX SHOWING THE POSITION OF THE HEART AND LUNGS.

1-12, ribs ; 11-12, floating ribs ; *s*, sternum ; *r*, rib ; *c.c*, costal cartilages ; *c*, clavicle ; *l*, lungs ; *α*, apex of heart ; *peric.* pericardium, cut edge.

be made into the pleura, the lung at once shrinks to a comparatively small size, and thus develops a great cavity between the two layers of the pleura. If a pipe be now fitted into the bronchus, and air blown through it, the

is very readily distended to its full size; but, on
left to itself, it collapses, the air being driven out
with some force. The abundant elastic tissues of
alls of the air-cells are, in fact, so disposed as to be
ly stretched when the lungs are full; and when the
of the distension is removed, this elasticity comes
lay and drives the greater part of the air out again.



2.—Transverse Section of the Chest, with the Heart and Lungs in place. (A little diagrammatic.)

dorsal vertebra, or joint of the backbone; *Ao. Ao'.* aorta, the top
rch being cut away in this section; *S.C.* superior vena cava; *P.A.*
nary artery, divided into a branch for each lung; *L.P. R.P.* left
ght pulmonary veins; *Br.* bronchi; *R.L. L.L.* right and left lungs;
gullet or œsophagus; *p.* outer bag of pericardium; *pl.* the two
of pleura; *v.* azygos vein.

e lungs are kept distended in the dead subject, so
as the walls of the chest are entire, by the pressure
atmosphere acting down the trachea, bronchi and
hioles upon the inner surfaces of the walls of the
i. For though the elastic tissue is all the while
g, as it were, at the layer of pleura which covers the
and attempting to separate it from that which lines

the chest, it cannot produce such a separation without developing a vacuum between these two layers. To effect this, the elastic tissue must pull with a force greater than that of the external air (or fifteen pounds to the square inch), an effort far beyond its powers, which do not equal

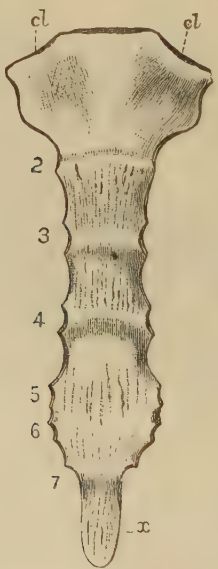


FIG. 43.—STERNUM VIEWED FROM THE FRONT.

1-7, points of attachment of first seven ribs ; *cl*. points of attachments of clavicles (collar-bones) ; *x*, lower projecting end of sternum.

one-fourth of a pound on the square inch. But the moment a hole is made in the pleura, the air enters into its cavity, the atmospheric pressure inside the lung is equalised by that outside it, and the elastic tissue, freed

its opponent, exerts its full power on the lung and lapses.

The Movements of Respiration.—The hinder ends e ribs are attached to the vertebral column so as to

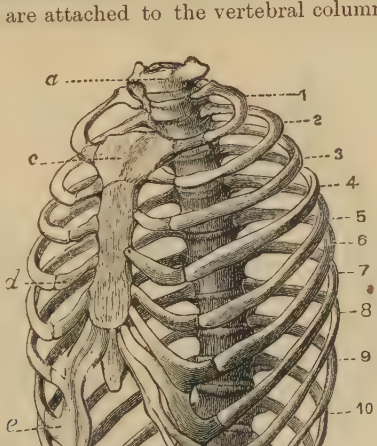


FIG. 44.—THE BONY WALLS OF THE THORAX.

vertebral column; 1-12, ribs; *c*, sternum; *d* costal cartilages; *e*, united cartilages of lower true ribs.

freely movable upon it. The front ends of the first pairs of ribs are connected either directly (first seven s), or indirectly (next three ribs), by the costal ilages to the sternum, the connection being therefore ible (Figs. 41, 44, 45). When left to themselves the ribs e a position which is inclined obliquely downwards and wards.

Two sets of muscles, called **intercostals**, pass between the successive pairs of ribs on each side. The outer set, called **external intercostals** (Fig. 45, *A*), run from the rib above, obliquely downwards and forwards, to the

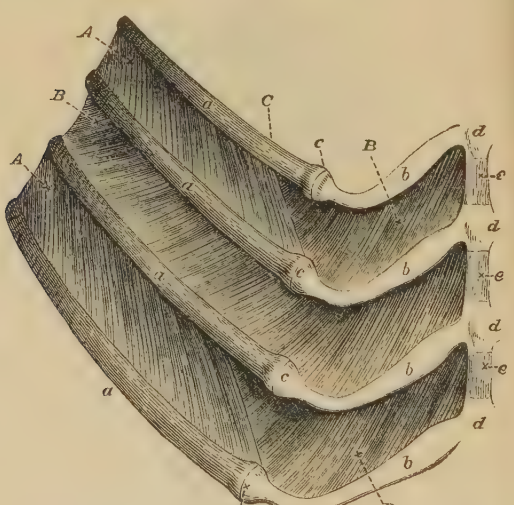


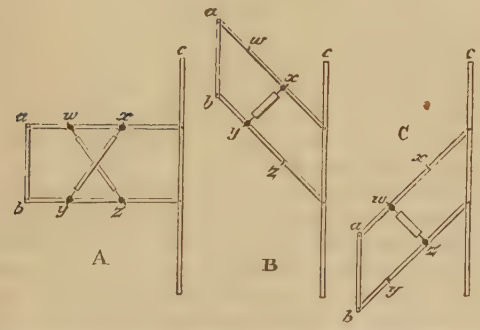
FIG. 45.—VIEW OF FOUR RIBS OF THE DOG WITH THE INTERCOSTAL MUSCLES.

a, the bony rib; *b*, the cartilage; *c*, the junction of bone and cartilage; *d*, unossified, *e*, ossified, portions of the sternum. *A*, external intercostal muscle; *B*, internal intercostal muscle. In the middle interspace, the external intercostal has been removed to show the internal intercostal beneath it.

rib below. The other set, **internal intercostals** (Fig. 45, *B*), cross these in direction, passing from the rib above, downwards and backwards, to the rib below.

The action of these muscles is somewhat puzzling at first, but is readily understood if the fact that *when*

e contracts, it tends to shorten the distance between its uds be borne in mind. Let *a* and *b* in Fig. 46, A, o parallel bars, representing two consecutive ribs, ble by their ends upon the upright *c*, which may be ted as the vertebral column at the back of the atus ; then a line directed from *x* to *y* will be inclined wards and forwards, and one from *w* to *z* will be ted downwards and backwards. Now it is obvious the figure that the distance between *x* and *y* is



46.—Diagram of Models illustrating the Action of the External and Internal Intercostal Muscles.

B, inspiratory elevation ; C, expiratory depression.

er in B than in A and much shorter than in C ; e when *x y* is shortened the bars will be pulled up the position C or A to or towards the position B. ersely, the shortening of *w z* will tend to pull the down from the position B or the position A to or ds the position C.

the simple apparatus just described be made of wood, s being placed at the points *x y*, and *w z* ; and an c band be provided with eyes which can be readily n to or taken off these hooks ; it will be found that

the band being so short as to be put on the stretch when hooked on to either *x y*, or *w z*, with the bars in the horizontal position, A, the elasticity of the band, when hooked on to *x* and *y*, will bring them up as shown in B; while, if hooked on to *w* and *z*, it will bring them down as shown in C.

Substitute the contractility of the external and internal intercostal muscles for the shortening of the band, in virtue of its elasticity, and the model will exemplify the action of these muscles; the external intercostals in shortening will tend to raise, and the internal intercostals to depress, the bony ribs.

Such a model, however, does not accurately represent the ribs, with their numerous and peculiar curves, and hence, while all are agreed that the external intercostals raise the ribs, the action of the internal intercostals is not by any means so certain.

The raising of the ribs which results from the action of the external intercostal muscles is further assisted by the contraction of certain other muscles, the **scaleni** and **levatores costarum**. The former are stretched between the cervical vertebræ and the first two ribs, and by their contraction serve to raise and fix these ribs. The latter are attached by their upper ends to the transverse processes of the last cervical and first eleven dorsal vertebræ, and each muscle is fastened by its lower end to the rib next below the vertebra from which the muscle itself springs. These muscles must also by their contraction raise the ribs.

By means of these several muscles the ribs can be raised from their naturally downward-slanting position into one more nearly horizontal. When this takes place, the front ends of the ribs must move not only upwards but forwards, and must therefore thrust the sternum slightly outwards, or away from the vertebral column. By this movement the size of the thorax is of course *increased from back to front*, an increase which may be easily felt by

ng one hand on the back and one on the chest of a
n who is breathing. Again, when the ribs are raised,
rib must evidently, by its upward motion, tend to
y the position previously held by the rib next above
ut the arched curve of each rib increases in size from
rst to the seventh pair of ribs, so that this upward
ment makes a rib with a larger arch take the place of
ith a smaller curve. This must clearly result in an
se in width of the thorax from side to side, an increase
may, as before, be readily felt by placing the hands
e opposite sides of the chest.

e floor of the thorax is formed by the diaphragm, a
partition situated between the thorax and the
nen, and always concave to the latter and convex to
former (Fig. 1, *D*). From its middle, which is
inous, muscular fibres extend downwards and outwards
e ribs, and two, especially strong masses, which are
l the *pillars of the diaphragm*, to the spinal column
47). When these muscular fibres contract, therefore,
tend to make the diaphragm flatter, and to increase
apacity of the thorax at the expense of that of the
nen, by pulling down the bottom of the thoracic box
48, *A*), or in other words when the diaphragm is
ned, the size of the thorax is *increased from above
wards*.

means then of the movements of the ribs and of the
ragm the size of the thorax may be increased in all
mensions. Let us now consider what must happen
e lungs when the thorax becomes larger. The lungs,
e have said (p. 137), are kept distended by the
ure of the atmosphere acting down the trachea and
ing the outer walls of each lung firmly pressed against
ner wall of the chest. This being so, if the wall of
horax tends to move away from the wall of the lung,
must do when the thorax is enlarged, then the wall
e lung must follow the wall of the thorax, air rushing
rough the trachea to increase the distension of the

elastic lungs to the required extent, and to prevent the formation of any vacuum between the two pleuræ. This drawing of air into the lungs constitutes an **inspiration.**

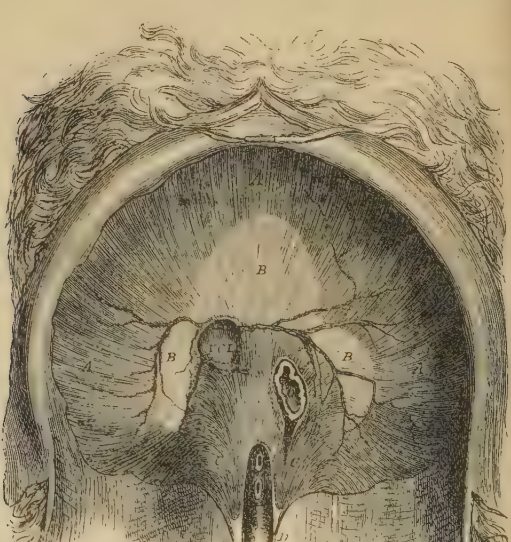


FIG. 47. – THE DIAPHRAGM OF A DOG VIEWED FROM THE LOWER OR ABDOMINAL SIDE.

V.C.I, the vena cava inferior; *O*, the œsophagus; *Ao*. the aorta; the broad white tendinous middle (*B.B.B*) is easily distinguished from the radiating muscular fibres (*A..A..A*) which pass down to the ribs and into the pillars (*C. D*) in front of the vertebræ.

At the end of each inspiration the diaphragm ceases to contract and the external intercostal muscles relax. So much of the elasticity of the lungs as was called into play by the contraction of the diaphragm and the

g of the ribs now comes into action ; air is driven
the lungs and the diaphragm rises to its former
n (Fig. 48, *B*), being partly also pushed up by the
inal viscera which were pushed down when the
agm contracted. At the same time gravity acting
ribs tends to lower them, and this is assisted by the
recoil of the lungs and of the tissues of the chest
hich had been put on the stretch during inspiration,
ssibly also by the contraction of the internal inter-
muscles. By these means air is driven out of
ngs, the forcing out of the air constituting an
ation, which taken together with an inspiration
up respiration.

s it appears that we may have either *diaphragmatic*
ation, or *costal respiration*. As a general rule, how-
the two forms of respiration coincide and aid one
er, the contraction of the diaphragm taking place at
me time with that of the external intercostals, and
laxation with their relaxation.

ordinary quiet respiration, inspiration is an active
ss depending on the contraction of muscles ; ex-
on, on the other hand, is rather due to a passive
of elastic structures which had been previously put
e stretch. But at times, as when taking violent
ise, the respiration becomes more forcible or, as it is
, "laboured." In this case many accessory muscles
into play to assist during inspiration in raising the
nd sternum ; being chiefly muscles stretched between
bs and parts of the vertebral column—above them
e back, and between the neck and the sternum in
At the same time expiration, from being passive
also becomes an active process, chiefly by the con-
on of certain muscles which connect the ribs and
t-bone with the pelvis, and form the front and side
of the abdomen, the abdominal muscles. They
expiration in two ways : first, directly, by pulling
the ribs ; and next, indirectly, by pressing the

viscera of the abdomen upwards against the under surface of the diaphragm, and so driving the floor of the thorax upwards.

It is for this reason that, whenever a violent expiratory effort is made, the walls of the abdomen are obviously flattened and driven towards the spine, the body being at the same time bent forwards.

In taking a deep inspiration, on the other hand, the walls of the abdomen are relaxed and become convex, the viscera being driven against them by the descent of the diaphragm—the spine is straightened, the head thrown back, and the shoulders outwards, so as to afford the greatest mechanical advantage to all the muscles which can elevate the ribs.

It is a remarkable circumstance that the mechanism of respiration is somewhat different in the two sexes. In men, the diaphragm takes the larger share in the process, the upper ribs moving comparatively little; in women, the reverse is the case, the respiratory act being more largely the result of the movement of the ribs.

Sighing is a deep and prolonged inspiration. "*Sniffing*" is a more rapid inspiratory act, in which the mouth is kept shut, and the air made to pass through the nose.

Hiccough is the result of a sudden inspiration, due to a contraction of the diaphragm, during which the glottis is suddenly closed and the column of air, striking on the closed glottis, gives rise to the well-known and characteristic sound.

Coughing is a violent expiratory act. A deep inspiration being first taken, the glottis is closed and then burst open by the violent compression of the air contained in the lungs by the contraction of the expiratory muscles, the diaphragm being relaxed and the air driven through the mouth. In *sneezing*, on the contrary, the cavity of the mouth being shut off from the pharynx by the approximation of the soft palate and the base of the tongue, the air is forced through the nasal passages.

Thus appears that the thorax, the lungs, and the
ea constitute a sort of bellows without a valve, in
the thorax and the lungs represent the body of the
ws, while the trachea is the pipe ; and the effect of
spiratory movements is just the same as that of

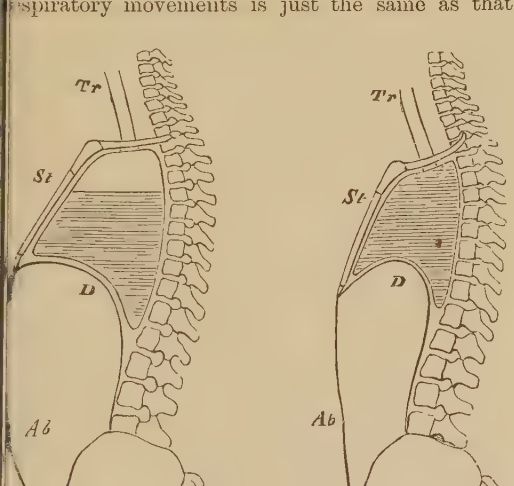


Fig. 48.—Diagrammatic Sections of the Body in
piration ; *B*, expiration ; *Tr*, trachea ; *St*, sternum ; *D*, diaphragm ;
dominal walls. The shading roughly indicates the stationary air.

pproximation and separation of the handles of the
ws, which drive out and draw in the air through the
There is, however, one difference between the
ws and the respiratory apparatus, of great importance
e theory of respiration, though frequently overlooked ;
hat is, that the sides of the bellows can be brought

close together so as to force out all, or nearly all, the air which they contain ; while the walls of the chest, when approximated as much as possible, still inclose a very considerable cavity (Fig. 48, *B*) ; so that, even after the most violent expiratory effort, a very large quantity of air is left in the lungs.

If an adult man, breathing calmly in the sitting position, be watched, the respiratory act will be observed to be repeated on an average about fifteen to seventeen times every minute ; but the frequency of repetition is very variable. Each act consists of certain components which succeed one another in a regular rhythmical order. First, the breath is drawn in or inspired, immediately afterwards it is driven out or expired ; and these successive acts are followed by a brief pause. Thus, just as in the rhythm of the heart, the auricular systole, the ventricular systole and then a pause follow in regular order ; so in the chest, the inspiration, the expiration, and then a pause succeed one another. But in the chest, unlike the case of the heart, the pause is generally very short compared with the active movement ; indeed, sometimes it hardly exists at all, a new inspiration following immediately on the close of expiration.

6. **The Amount of Air Respired.**—At each inspiration of an adult well-grown man about 500 c.c. (20 to 30 cubic inches) of air are inspired ; and at each expiration the same, or a slightly smaller, volume (allowing for the increase of temperature of the air so expired) is given out of the body. To this the name of **tidal air** has been conveniently given.

The amount of air which, as already pointed out, cannot be got rid of by even the most violent expiratory effort and is called **Residual air**, is, on the average, about 1,500 c.c. (from 75 to 100 cubic inches).

About as much more in addition to this remains in the chest after an ordinary expiration, and is called **Supplemental air.**

ns it follows that, after an ordinary inspiration, +1,500+500=3,500 c.c. (100+100+30=230 cubic s) may be contained in the lungs. By taking the st possible inspiration, another 1,500 c.c. (100 cubic s), called **Complemental air**, may be added.

e sum of the supplemental, tidal, and complemental ounts to about 3,500 to 4,000 c.c. (230 to 250 cubic s), and is a measure of what is known as the *respiratory al capacity*. It varies according to a person's height, ht, and age.

results from these data that the lungs, after an ary inspiration, contain about 3,500 c.c. (230 cubic s) of air, and that only about one-seventh to one- h of this amount is breathed out and taken in again at ext inspiration. Apart from the circumstance, then, he fresh air inspired has to fill the cavities of the er part of the mouth, and the trachea, and the chi, if the lungs were mere bags fixed to the end of bronchi, the inspired air would descend so far only occupy that one-fourteenth to one-sixteenth part of bag which was nearest to the bronchi, whence it l be driven out again at the next expiration. But as bronchi branch out into a prodigious number of chial tubes, the inspired air can only penetrate for a in distance along these, and can never reach the ells at all.

lus the residual and supplemental air taken together under ordinary circumstances, *stationary*—that is to the air comprehended under these names merely s its outer limit in the bronchial tubes, as the chest es and contracts, without leaving the lungs, and is e called **stationary air**; the *tidal* air, alone, being which leaves the lungs and is renewed in ordinary iration.

is obvious, therefore, that the business of respiration ssentially transacted by the stationary air, which plays part of a middleman between the two parties—the

blood and the fresh tidal air—who desire to exchange their commodities, carbonic acid for oxygen, and oxygen for carbonic acid.

Now there is nothing interposed between the fresh tidal air and the stationary air; they are gaseous fluids, in complete contact and continuity, and hence the exchange between them must take place according to the ordinary laws of gaseous diffusion.

Thus, the stationary air in the air-cells gives up oxygen to the blood, and takes carbonic acid from it, though the exact mode in which the change is effected is not thoroughly understood. By this process it becomes loaded with carbonic acid, and deficient in oxygen, though to what precise extent is not known. But there must be a very much greater excess of the one, and deficiency of the other, than is exhibited by inspired air, seeing that the latter acquires its composition by diffusion in the short space of time (four or five seconds) during which it is in contact with the stationary air.

7. The Changes of Air in Respiration.—Expired air differs from the air inspired in the following particulars.

(i) Speaking generally, whatever be the temperature of the external air, that expired tends to be nearly as hot as the blood, or has a temperature of about 37 C. (98·6° F.).

(ii) However dry the external air may be, that expired is nearly, or quite, saturated with watery vapour. This vapour is not derived from the stationary air, but from the walls of the outer air passages, so that the inspired air is practically saturated with aqueous vapour before it reaches the bronchi.

(iii) While ordinary inspired air contains in 100 volumes—

Oxygen	Nitrogen	Carbonic Acid
20·96	79·00	·04

mposition of expired air is on the average in 100 nes—

Oxygen	Nitrogen	Carbonic Acid
16·50	79·50	4·00

us, speaking roughly, air which has been breathed has gained 4 per cent. of carbonic acid and lost rather than 4 per cent. of oxygen, the quantity of nitrogen practically unchanged.

Expired air contains, in addition, small quantities animal matter" or organic impurities of a highly posable kind. Nothing is known of their nature, hey are probably the chief cause, why air which has breathed once is extremely unwholesome if breathed ond time; hence they are of great importance in con- ion with ventilation (see p. 168).

The volume of the tidal air is but little altered by breathed, because the two parts of oxygen in the mic acid (CO_2) occupy the same volume as the car- acid itself, or in other words the volume of the mic acid is equal to that of the oxygen contained in But as a matter of fact very close analysis of the red air shows firstly that the volume of oxygen h disappears is always slightly greater than the me of carbonic acid which takes its place. This ecause all the oxygen taken in does not go to carbonic acid; some of it unites with hydrogen to water and some with other elements such as sulphur. ce the volume of the expired air is slightly ($\frac{1}{50}$) less that of the inspired air. In the second place careful ysis shows that the nitrogen in expired air may vary slightly: sometimes it is a little in excess of, some- s slightly less than, that inspired, and sometimes it ains unaltered.

The Amount of Waste which leaves the Lungs. — ut 10,000 litres (from 350 to 400 cubic feet) of air are ed through the lungs of an adult man taking little or

no exercise, in the course of twenty-four hours, and are charged with carbonic acid, and deprived of oxygen, to the extent of about four per cent. This amounts to about 450 litres (16 cubic feet) of the one gas taken in, and of the other given out. Thus, if a man be shut up in a close room, having the form of a cube seven feet in the side, every particle of air in that room will have passed through his lungs in twenty-four hours, and a fifth of the oxygen it contained will be replaced by carbonic acid.

The quantity of carbon eliminated in the twenty-four hours is pretty nearly represented by a piece of pure charcoal weighing 225 grammes (eight ounces).

The quantity of water given off from the lungs in the twenty-four hours varies very much, but may be taken on the average as rather less than 250 c.c. (half a pint, or about nine ounces). It may fall below this amount, or increase to double or treble the quantity.

The air expired during the first half of an expiration contains less carbonic acid than that expired during the second half. Further, when the frequency of respiration is increased without altering the volume of each inspiration, though the percentage of carbonic acid in each expiration is diminished, it is not diminished in the same ratio as that in which the number of inspirations increases ; and hence more carbonic acid is got rid of in a given time.

Thus, if the number of inspirations per minute is increased from fifteen to thirty, the percentage of carbonic acid evolved in the second case remains more than half of what it was in the first case, and hence the total evolution is greater.

The activity of the respiratory process is greatly modified by the circumstances in which the body is placed. Thus, cold greatly increases the quantity of air which is breathed, the quantity of oxygen absorbed, and of carbonic acid expelled : exercise and the taking of food have a corresponding effect.

proportion to the weight of the body, the activity of respiratory process is far greatest in children, and nishes gradually with age.

e excretion of carbonic acid is greatest during the and gradually sinks at night, attaining its minimum t midnight, or a little after.

leed it would appear that the rule that the quantity ygen taken in by respiration is, approximately, equal at given out by expiration, only holds good for the result of twenty-four hours' respiration. Much more en appears to be given out during the day-time (in nation with carbon as carbonic acid) than is ab- d ; while, at night, much more oxygen is absorbed is excreted as carbonic acid during the same period. it is very probable that the deficiency of oxygen rds the end of the waking hours, which is thus uced, is one cause of the sense of fatigue which comes t that time. This difference between day and night owever, not constant, and appears to depend a good on the time when food is taken.

e quantity of oxygen which disappears in proportion e carbonic acid given out, is greatest in carnivorous, in herbivorous animals —greater in a man living on sh diet, than when the same man is feeding on vege- e matters.

The Nature of the Respiratory Changes in the gs and Tissues.—The essential difference between ous and arterial blood is, as we have previously ex- ned, entirely dependent upon the relative amounts of two gases, oxygen and carbonic acid, which they re- tively contain. We have also pointed out where the nges from arterial to venous blood and *vice versa*, take e, and have indicated the general causes of the con- ion as being an interchange between the blood and ues on the one hand, and between the blood and stationary air in the lungs on the other. But we e not so far dealt with the nature of the processes

no exercise... effecting the interchange, and to these we charged w turn our attention.

the exact understanding of certain facts and principles 450 to the behaviour of gases towards each other and towards liquids with which they may be in contact is essential as a preliminary.

When a gas is enclosed in a vessel, it exerts a pressure on its walls which is measured by the height of the column of mercury which it can support in a vertical tube connected with the vessel. If two gases are mixed in the vessel, each gas exerts its own pressure just as if the other gas were not present ; the total pressure of the two gases is therefore *equal to the sum of their separate pressures.* The pressure due to each gas in the mixture is called the **partial pressure** of that gas, and is *proportional to the quantity* of the gas. Hence if the total pressure of the mixture is measured and its composition is determined by analysis the partial pressure of each gas is at once known. Take for instance, ordinary air when the barometer stands at 760 mm. (30 inches of mercury). The partial pressure of the oxygen is $\frac{21}{100} \times 760 = 159{\cdot}6$ mm. (6·3 inches of mercury), and that of the nitrogen is $\frac{79}{100} \times 760 = 600{\cdot}4$ mm. (23·7 inches of mercury).

When a gas is in contact with a liquid some of the gas is absorbed by the liquid, the amount being dependent on the pressure of the gas. If *two* gases are in contact with the *same* liquid they will be absorbed in quantities proportional to their respective partial pressures in the space over the liquid, and when the absorption is complete the partial pressures of the gases in the liquid are the same as the partial pressures of the gases in the space. If the partial pressure of one of the gases be made less in the space over the liquid, then some of that gas will make its exit from the liquid ; and if its partial pressure be, on the other hand, increased, then more of that gas will enter the liquid. Thus we see that changes in the partial

sures of the gases in contact with the liquid determine exit and entry of those gases from and into the liquid. ever, since gases diffuse readily through thin porous , the statements we have just made will, broadly ing, hold equally good in the case when the surface fluid is separated from the neighbouring gases by moist, porous film.

air in the alveoli of the lungs is a mixture of gases rated by the thin, moist, filmy wall of the capillaries the venous blood brought to them by the pulmonary ; and what we have now to consider is whether, absence of any other obvious cause, the differences tial pressure between the gases in that air and the gases in that blood are sufficient to account for interchange by which the venous blood becomes ial.

ow the oxygen and carbonic acid in blood are not in solution but largely in combination with certain ituents of the corpuscles and plasma. Hence the sures they exert are much less than they would be if were in simple solution. But on the other hand the ounds formed by these gases in the blood are very ble and easily dissociated or broken up, so that ficient difference of partial pressure on the surface of lood may still easily start the interchange between lood and the alveolar air and between the blood he tissues.

he composition of alveolar air has not been determined as yet because it is not so far possible to collect tion of air direct from the alveoli. But from the position of expired air we can at once determine the al pressures of the oxygen and carbonic acid in it, although the partial pressure of the oxygen in lar air must be less and of carbonic acid greater in expired air, there are reasons for supposing that difference is not great. By applying the data thus ned we find that venous blood in contact with

oxygen at the partial pressure it probably has in alveolar air becomes arterialised as regards its oxygen. And the entry of the oxygen is further assisted by the fact that it is stowed away in loose chemical combination in the red corpuscles. Similarly we may say that the exit of carbonic acid is due to the difference between the (lower) partial pressure of carbonic acid in the alveolar air and the (higher) partial pressure it has in the venous blood; but the case is not quite so clear as it is in respect of the entry of oxygen. For the partial pressure of carbonic acid in alveolar air is not inconsiderable, and its exit from the blood is opposed by the fact that it is in loose combination with some constituent of the plasma.

The blood thus fully arterialised is whirled away to the tissues, where it becomes once more venous. In the tissues the causes of the change are much more easily understood, for the living tissues are greedy of oxygen, which they stow away in compounds so stable that they give up no oxygen to the vacuum of even the most powerful pump; the partial pressure of oxygen in the tissues is in fact zero. Hence oxygen readily passes over from the arterial blood. Again, the living tissues are always producing carbonic acid in greater or less amount according as they are more or less active; the partial pressure of carbonic acid is therefore high in the tissues and quite sufficient to account for the passage of this gas from them into the neighbouring arterial blood.

The amount of oxygen left in venous blood is dependent on the varying activity of the tissues, and this is the reason why the volume of this gas was given (p. 124) as varying from eight to twelve volumes in each hundred volumes of venous blood.

10. The Nervous Mechanism of Respiration.—Of the various mechanical aids to the respiratory process, the nature and workings of which have now been described, one, the elasticity of the lungs, is of the nature of a dead, constant force. The action of the rest of the

tus is under the control of the nervous system, and from time to time.

the nasal passages cannot be closed by their own , air has always free access to the pharynx ; but the , or entrance to the windpipe, is completely under ntrol of the nervous system—the smallest irritation the mucous membrane in its neighbourhood being ed, by its nerves, to that part of the cerebro-spinal hich is called the **spinal bulb** or **medulla oblata** (see Lesson XI.). The spinal bulb thus stimugives rise, by a process which will be explained ter, termed *reflex action*, to the contraction of the es which close the glottis, and commonly, at the time, to a violent contraction of the expiratory es, producing a cough (see p. 146). The muscular of the smaller bronchial tubes are similarly under the l of the bulb, sometimes contracting so as to narrow sometimes relaxing so as to permit the widening of ronchial passages.

se, however, are mere incidental actions. The whole atory machinery is worked by a nervous apparatus. what has been said, it is obvious that there are analogies between the circulatory and the respiratory atus. Each consists, essentially, of a kind of pump distributes a fluid (gaseous in the one case, liquid e other) through a series of ramified distributing to a system of cavities (capillaries or air-cells), the e of the contents of which is greater than that of ubes. While the heart however is a force-pump, the atory machinery represents a suction-pump.

each the pump is the cause of the motion of the though that motion may be regulated, locally, by ontraction or relaxation, of the muscular fibres ined in the walls of the distributing tubes. But, the rhythmic movement of the heart chiefly depends an apparatus placed within itself, which is then con- l by the central nervous system, that of the respi-

ratory apparatus results mainly from the operation of a nervous centre lodged in the spinal bulb, which has been called the **respiratory centre.**

This centre is situated (see Fig. 49, *R.C.*) close to the two previously described (Figs. 22 and 23) as the vaso-motor and cardio-inhibitory centres (pp. 69 and 75). Impulses arise in this centre, pass down the spinal cord, and leaving the cord along certain nerves, reach the various muscles by whose contractions the movements of respiration are produced. The respiratory muscles contract only when they receive these impulses, and therefore all the movements of respiration depend upon the activity of this centre, and cease at once on injury of this part of the spinal bulb.

The action of the centre is primarily *automatic;* in other words the impulses it sends out appear to be the result of changes *started within itself*, in the same way that the beat of the heart is automatic as the outcome of changes started in the muscle-tissue of which it is made up. This primary automatism of the respiratory centre is subject, however, to control by impulses reaching it from outlying parts of the body, and more particularly by changes in the condition or quality of the blood which circulates in the capillaries of the centre itself, in a way to be described presently.

The intercostal muscles are supplied by **intercostal nerves** coming from the spinal cord in the region of the back (Fig. 49, *ICN*, *ICN*, *ICN*), and the muscular fibres of the diaphragm are supplied by two nerves, one on each side, called the **phrenic nerves** (Fig. 49, *Phr.*), which starting from certain of the spinal nerves in the neck, dip into the thorax at the root of the neck, and find their way through the thorax by the side of the lungs to the diaphragm, over which they are distributed. Now from the nervous respiratory centre in the spinal bulb impulses at repeated intervals descend along the upper part of the spinal cord and, passing out by the phrenic and intercostal nerves

tively, reach the diaphragm and the intercostal es. These immediately contract, and thus an ation takes place. Thereupon the impulses cease, e replaced by other impulses, which though starting the same centre pass, not to the diaphragm and al intercostal muscles, but to other, expiratory, s, which they throw into contraction, and thus tion is brought out. As a general rule the inspira- mpulses are much stronger than the expiratory; l, in ordinary quiet breathing expiration is chiefly ht about, as we have seen, by the elastic recoil of ngs and chest walls; these need no nervous impulses them at work, as soon as the inspiratory impulses and the diaphragm and other inspiratory muscles off contracting, they come of themselves into action. in laboured breathing, very powerful expiratory ses may leave the respiratory centre and pass to the s muscles whose contractions help to drive the air the chest.

ry day experience shows that no function of the body e obviously subject to sudden and marked changes is the respiration. It is quickened by exercise, ened or slowed by emotions; hurried by stimulation skin, as by a dash of cold water, or brought to a still by stimulating the mucous membrane of the by a pungent vapour such as strong ammonia. The es involved in sneezing, laughing, coughing, &c., are und and peculiar. Finally we can control our ation by an effort of the will within very wide limits in almost any desired way. The mechanism ed in the production of all these changes is corre- ingly complicated; but certain broad facts are fairly e, and to these we may now turn.

e main trunk of the **vagus** nerve (see Lesson XI.) off a branch to the larynx as it passes down the neck 49, *S.Lr.*). If the vagus be cut *below the point of* this nerve (as at *x*, Fig. 49) and the upper (central)

end (*y*, Fig. 49), connected with the spinal bulb be stimulated, the respiration becomes hurried. Thus we have in

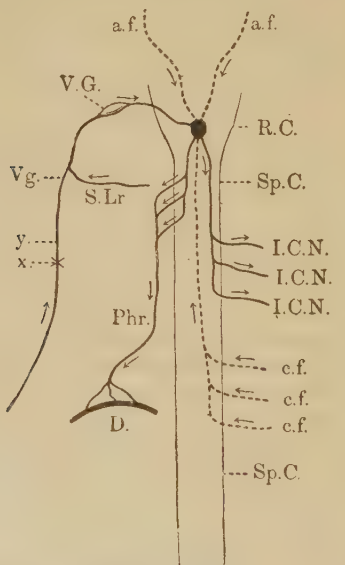


FIG. 49.—DIAGRAM TO ILLUSTRATE THE POSITION OF THE RESPIRATORY CENTRE, THE CONNECTIONS OF THIS CENTRE WITH THE INTERCOSTAL MUSCLES AND DIAPHRAGM, AND THE PATHS BY WHICH IMPULSES PASS TO THE CENTRE FROM OUTLYING PARTS OF THE BODY AND FROM THE BRAIN.

Sp.C, *Sp.C*, spinal cord; *R.C*, respiratory centre in the bulb; *ICN*, *ICN*, *ICN*, three intercostal nerves; *Phr.* one phrenic nerve passing to the diaphragm *D*; *Vg.* vagus nerve; *V.G*, ganglion of vagus nerve; *S.Lr*, superior laryngeal nerve. The dotted lines, *cf*, *cf*, *cf*, indicate paths of conduction for impulses to the respiratory centre from some part of the body such as the skin; the dotted lines, *af*, *af*, similar paths from the brain to the centre. The arrows show the direction in which impulses travel along each nerve or path.

the *vagus* a nerve such that impulses passing up it may *quicken* the respiration by their action on the respiratory centre.

on the other hand the branch of the vagus supplying larynx, the **superior laryngeal nerve**, be cut, and central end be stimulated, the result is that the ration may be *slowed*, even to a *complete cessation* of spiratory movements.

the case of the vagus impulses seem to be ordinarily s passing up it to facilitate the action of the respira- centre, for if the vagus nerves be simply cut, the ration becomes at once extremely slow.

ese two nerves may be taken as typical of their kind, me quickening, the other slowing the respiration. similar nerves run to the respiratory centre from all of the body, notably from the skin, also from the , and by their varied action largely determine the ifold changes which the respiratory movements from to time undergo.

Influence of Blood-Supply on the Respiratory tre. Dyspnœa and Asphyxia.—The function of ration has for its one great object the conversion of us into arterial blood. Hence we might expect that echanism which controls it should be adjusted so as e extremely sensitive to the varying condition or ity of the fluid (blood), whose gaseous composition it o regulate. This expectation is justified by facts, for ugh the respiratory centre is keenly responsive to ulses brought to bear upon it along various nerves, it en more so to the influence exerted by the varying ity of the blood circulating in the capillaries of the l bulb. Thus, when by any means the blood becomes arterialised than it should be, the respiratory centre this change, and is at once stimulated to greater ity in the endeavour, by an increased force and uency of the respiratory movements, to restore the d to its proper condition. In other words, venous d makes the respiratory centre work faster and more rously.

nc blood becomes more venous whenever the free

access of air to the lungs is interfered with; as, for instance, when a man is strangled, drowned, or choked by food or other obstacle in the trachea. But the blood may become unusually venous by means less violent than the above. Since the rapidity of diffusion between two gaseous mixtures depends on the difference of the proportions in which their constituents are mixed, it follows that the more nearly the composition of the tidal air approaches that of the stationary air, the slower will be the diffusion of oxygen inwards, and of carbonic acid outwards, and the more deficient in oxygen and overcharged with carbonic acid will the air in the alveoli become. Thus by breathing in a confined space, the oxygen in the tidal air is *gradually* diminished and the carbonic acid *gradually* increased until at length a point is reached when the change effected in the stationary air is too slight to enable it to supply the pulmonary blood with oxygen, and to relieve it of carbonic acid to the extent required for its proper arterialisation.

When from any of the above causes the blood sent to the respiratory centre is more venous than usual, the centre is stimulated and the respiratory movements become quicker and more forcible. This condition is usually spoken of as **dyspnœa**, or laboured breathing. It is characterised by the increased force and frequency with which both the inspiratory and expiratory muscles contract. If the offending cause of dyspnœa be not removed, the blood becomes more and more venous. By this means the respiratory centre is spurred on to still greater activity. Not only do the ordinary muscles of respiration contract more vigorously, but the accessory muscles (p. 145) come into more prominent play, and *chiefly those which assist expiration*. Still later, nearly all the muscles of the body are thrown into a state of violent contracting activity, and with the onset of these **convulsions** dyspnœa passes over into **asphyxia**. The violence of the convulsive movements speedily leads to exhaustion, and the con-

sions cease. After this stage is reached, a long-drawn piration takes place at intervals; but the intervals come longer and longer and the inspiratory movements e and more feeble until the last breath is taken and thing ends with an expiratory gasp.[1]

fter death by asphyxia the blood throughout the ie body is of course venous. The right side of the rt, the great (systemic) veins and the pulmonary ries are highly distended with blood, while the left of the heart is empty. This condition of the vascular em is brought about largely by an obstruction to the ally easy flow of blood through the lungs, which is due a constriction of their small arteries caused by the ulation resulting from the venosity of the blood. But s helped by the unusually forcible drawing of blood the great veins which results from the increased e of the respiratory movements (see p. 166).

Venous blood is distinguished from arterial by two tures, by having less oxygen and more carbonic acid. nce, in asphyxia, two influences of a distinct nature co-operating; one is the *deprivation of oxygen*, the er is the *excessive accumulation of carbonic acid* in the od. Oxygen starvation and carbonic acid poisoning, h of which is injurious in itself, are at work together; of these, the lack of oxygen is the real cause of hyxia.

The effects of oxygen starvation may be studied sepaely, by placing a small animal under the receiver of an pump and exhausting the air; or by replacing the by a stream of hydrogen or nitrogen gas. In these es no accumulation of carbonic acid is permitted, but, the other hand, the supply of oxygen soon becomes ufficient, and the animal quickly dies with all the mptoms of asphyxia. And if the experiment be made another way, by placing a small mammal, or bird, in

[1] The term asphyxia is sometimes used to include all the above three ges, from the onset of dyspnœa until death ensues.

air from which the carbonic acid is removed as soon as it is formed, the animal will nevertheless die asphyxiated as soon as the amount of oxygen is reduced to 10 per cent. or thereabouts.

The directly poisonous effect of carbonic acid, on the other hand, has been very much exaggerated. A very large quantity of pure carbonic acid (10 to 15 or 20 per cent.) may be contained in air, without producing any very serious immediate effect, if the quantity of oxygen be simultaneously increased.

Moreover such symptoms as do occur when the carbonic acid in the air breathed is increased without any corresponding decrease in the oxygen, are not exactly those of asphyxia but are said to resemble rather those of narcotic poisoning. So that the chief cause of asphyxia in strangling, drowning, or choking, or however produced, is the diminution of the oxygen in the air of the lungs and consequently a diminution of the oxygen in the blood.

And that it is the lack of oxygen which is the important thing is further shown by the asphyxiating effects of certain poisonous gases. Thus sulphuretted hydrogen, so well known by its offensive smell, has long had the repute of being a positive poison. But its evil effects appear to arise chiefly, if not wholly, from the circumstance that its hydrogen combines with the oxygen carried by the blood-corpuscles, and thus gives rise, indirectly, to a form of oxygen starvation.

Carbonic oxide gas (carbon monoxide, CO) has a much more serious effect, as it turns out the oxygen from the blood-corpuscles, and forms a very stable combination of its own with the hæmoglobin. The compound thus formed is only very gradually decomposed by fresh oxygen, so that if any large proportion of the blood-corpuscles be thus rendered useless, the animal dies before restoration can be effected. Badly made common coal gas sometimes contains 20 to 30 per cent. of carbon

noxide; and, under these circumstances, a leakage the pipes in a house may be extremely perilous to

2. The Influence of Respiration on the Circulation. Just as there are certain secondary phenomena which company, and are explained by, the action of the heart, here are secondary phenomena which are similarly re- ed to the working of the respiratory apparatus. Of se the chief is the effect of the inspiratory and expi- ory movements upon the circulation.

In consequence of the elasticity of the lungs, a certain e must be expended in distending them, and this force found experimentally to become greater and greater more the lung is distended; just as, in stretching a ce of india-rubber, more force is required to stretch it good deal than is needed to stretch it only a little. nce, when inspiration takes place, and the lungs are tended with air, the heart and the great vessels in the st are subjected to a less pressure than are the blood- ssels of the rest of the body.

For the pressure of the air contained in the lungs is actly the same as that exerted by the atmosphere upon surface of the body; that is to say, fifteen pounds on square inch. But a certain amount of this pressure erted by the air in the lungs is counterbalanced by the sticity of the distended lungs. Say that in a given dition of inspiration a pound[1] pressure on the square ch is needed to overcome this elasticity, then there will only fourteen pounds pressure on every square inch the heart and great vessels. And hence the pressure the blood in these vessels will be one pound per square ch less than that on the veins and arteries of the rest of e body, which lie outside the thorax. If there were no rtic, or pulmonary, valves, and if the structure of the

[1] A "pound" is stated here for simplicity's sake. As a matter of fact e pressure required is much less than this, not more than 2 or 3 nces.

vessels, and the pressure upon the blood in them, were everywhere the same, the result of this excess of pressure on the surface would be to drive all the blood from the arteries and veins of the rest of the body into the heart and great vessels contained in the thorax. And thus the diminution of the pressure upon the thoracic blood cavities produced by inspiration, would, practically, suck the blood from all parts of the body towards the thorax. But the suction thus exerted, while it hastened the flow of blood to the heart in the veins, would equally oppose the flow from the heart to the arteries, and the two effects might balance one another.

As a matter of fact, however, we know—

(1) That the blood in the great arteries is constantly under a very considerable pressure, exerted by their elastic walls; while that of the veins is under little pressure.

(2) That the walls of the arteries are strong and resisting, while those of the veins are weak and flabby.

(3) That the veins have valves opening towards the heart; and that, during the diastole, there is no resistance of any moment to the free passage of blood into the heart; while, on the other hand, the cavity of the arteries is shut off from that of the ventricle, during the diastole, by the closure of the semilunar valves.

Hence it follows that equal pressures applied to the surface of the veins and to that of the arteries must produce very different effects. In the veins the pressure is something which did not exist before; and partly from the presence of valves, partly from the absence of resistance in the heart, partly from the presence of resistance in the capillaries, it all tends to accelerate the flow of blood *towards* the heart. In the arteries, on the other hand, the pressure is only a fractional addition to that which existed before; so that, during the systole, it only makes a comparatively small addition to the resistance which has to

vercome by the ventricle ; and during the diastole, it
radds itself to the elasticity of the arterial walls in
ing the blood onwards towards the capillaries, inas-
h as all progress in the opposite direction is stopped
he semilunar valves.

is, therefore, clear, that the inspiratory movement,
he whole, helps the heart, inasmuch as its general
lt is to drive the blood the way that the heart
pels it.

expiration, the difference between the pressure of
atmosphere on the surface, and that which it exerts
he contents of the thorax through the lungs, becomes
and less in proportion to the completeness of the ex-
tion. Whenever, by the ascent of the diaphragm and
descent of the ribs, the cavity of the thorax is so far
inished that pressure is exerted on the great vessels,
veins, owing to the thinness of their walls, are especi-
affected, and a check is given to the flow of blood
hem, which may become visible as a *venous pulse* in
great vessels of the neck. In its effect on the arterial
aks, expiration, like inspiration, is, on the whole,
urable to the circulation ; the increased resistance to
opening of the valves during the ventricular systole
ng more than balanced by the advantage gained in the
lition of the expiratory pressure to the elastic reaction
he arterial walls during the diastole.

When the skull of a living animal is laid open and the
in exposed, the cerebral substance is seen to rise and
l synchronously with the respiratory movements ; the
e corresponding with expiration, and being caused by
e obstruction thereby offered to the flow of the blood in
e veins of the head and neck.

The effects of the respiratory movements on the flow of
od towards the heart must be the same for any other
ucture contained in the thorax and connected with
ssels lying outside the thorax. Now the thoracic duct
a large, thin-walled tube placed inside the thorax and

communicating with the lymphatic vessels which lie in the abdomen, and, further, it is plentifully supplied with valves. At inspiration the reduction of pressure on the outside of the duct draws lymph up into it from the abdominal lymphatic vessels. At expiration, the lymph cannot pass down again, owing to the valves in the duct, and is therefore sent on towards the junction of the duct with the venous system. Hence the respiratory movements on the whole are a not unimportant aid to the onward flow of lymph (see p. 92).

13. Ventilation.—In the case of breathing the same air over and over again the deprivation of oxygen, and the accumulation of carbonic acid, cause injury, long before any signs of even dyspnœa are observed. Under these circumstances uneasiness and headache arise when less than 1 per cent. of the oxygen of the air is replaced by other matters; the symptoms in this case however are due not so much to the diminution of oxygen or the increase of carbonic acid, as to the poisonous effects of the various organic matters present in expired air which, though existing in minute quantities, have a powerfully deleterious action. It need hardly be added that the persistent breathing of such air tends to lower all kinds of vital energy, and predisposes to disease. Hence the necessity of sufficient air and of ventilation for every human being.

The object of ventilation is to prevent the accumulation of these organic impurities (p. 151) and any deficiency of oxygen, such as may arise from burning gas in a room for purposes of illumination. Since the organic matter does not admit of direct estimation, the percentage of carbonic acid in the air is usually taken as an indirect measure of its amount, and this is at the same time a measure of the deficiency of oxygen. Air which has been fouled by breathing is injurious if it contains more than ·05 per cent. of carbonic acid. Knowing the amount of air passed through the lungs in one hour and the amount of

c acid it contains (p. 152), calculation easily shows
the percentage of carbonic acid is to be kept down
limit of ·05 per cent. a man should live in a room
apacity is not less than 28,000 litres (1,000 cubic
nd into which at least 60,000 litres (2,000 cubic
fresh air are admitted each hour.[1]

[1] ical room nine feet high, wide and long, contains only 729
t of air.

LESSON V

THE SOURCES OF LOSS AND OF GAIN TO TH BLOOD

1. General Review of the Gain and Loss.—Th blood which has been aërated, or arterialised, by th process described in the preceding Lesson, is carried fro the lungs by the pulmonary veins to the left auricle, an is then forced by the auricle into the ventricle, and by th ventricle into the aorta. As that great vessel travers the thorax, it gives off several large arteries, by means which blood is distributed to the head, the arms, and th walls of the body. Passing through the diaphragm (Fi 47, *Ao.*), the aortic trunk enters the cavity of the abdome and becomes what is called the *abdominal aorta*, fro which vessels are given off to the viscera of the abdome Finally, the main stream of blood flows into the *ili* arteries, whence the viscera of the pelvis and the legs a supplied.

Having in the various parts of the body traversed t ultimate ramifications of the arteries, the blood, as we ha seen, enters the capillaries. Here the products of t waste of the tissues constantly pour into it ; and, as t blood is everywhere full of corpuscles, which, like other living things, decay and die, the products of th decomposition also tend to accumulate in it, but these a insignificant compared to those coming from the gr mass of the tissues. It follows that, if the blood is to kept pure, the waste matters thus incessantly poured in

rated in it, must be as constantly got rid of, or
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distinct sets of organs are especially charged with
ce of continually removing or "excreting" waste
from the blood. They are the *lungs*, the *kidneys*,
skin (see Lesson I.). These three great organs
refore be regarded as so many drains from the
as so many channels by which it is constantly
ubstance.

e other hand, the blood, as it passes through the
es, is constantly giving up material by exudation
the capillary walls into the surrounding tissues,
to supply them with nourishment, and thus in this
is constantly losing matter.

material which the blood loses by giving it up to
ues consists of complex organic bodies, such as
s, fats, carbohydrates, and various substances
tured out of these, of certain salts, of a large
of water, and lastly of oxygen.

material which the blood loses by giving it up to
n, lungs and kidneys, passes away from these
as water, as carbonic acid, as peculiar organic
ces of which one, called *urea*, is much more
nt than the others, and as certain inorganic salts.
g generally we may say that these organs together
from the blood, water, carbonic acid, urea and

ner kind of loss takes place from the surface of
y generally, and from the interior of the air-
s. Heat is constantly being given off from the
by radiation, evaporation, and conduction: from
er, chiefly by evaporation; and the loss of heat in
e is borne by the blood passing through the skin
-passages respectively. Besides this a certain
of heat is lost by the urine and fæces which are
warm when they leave the body.

ne side of gain we have, in the first place, the

various substances which are the products of the activity of the several tissues, muscles, brain, glands, &c., and which pass from the tissues into the blood. We may speak of these as waste products, and one of them which is produced by all the tissues, namely carbonic acid, is emphatically a waste product and is got rid of as soon as possible. But some of the substances which are returned to the blood from the tissues are not wholly useless matters to be thrown off as rapidly as possible ; they are capable of being used up again by some tissue or other. Thus, as we shall see, the liver, at certain times at all events, returns to the blood a certain quantity of sugar which is made use of in other parts of the body, and similarly the spleen, while it takes up certain substances from the blood, gives back to the blood certain other substances which we can hardly speak of as waste matters in the sense of being useless material fit only to be at once thrown away.

In the second place, the blood is continually receiving from the alimentary canal the materials arising from the food which has been digested there. As we shall see, some of this material passes directly from the cavity of the alimentary canal into the blood, but some of it goes in a more roundabout way through what are called the lacteals or lymphatics. On its way to the blood this latter is joined by material which, escaping from the blood and not used by the tissues, or passing from the tissues directly into the lymphatics, is carried back to the blood by the thoracic duct (see Lesson II., p. 87).

In the third place, the blood is continually gaining oxygen from the air through the lungs.

Then again the blood, while it loses heat by the skin and lungs, gains heat from the tissues. As we have already seen (Lesson I., p. 25) oxidation is continually going on in various parts of the body, and by this oxidation heat is continually being set free. Some of this oxidation may take place in the blood itself ; we do not know exactly how

nt probably very little. The greater part of the generated in the tissues, in the muscles and e, and is given up by the tissues to the blood. we may say that the blood gains heat from the

several gains and losses are for the most part constantly, but are greater at one time than at Thus the gain to the blood from the alimentary much greater some time after a meal than just he next meal, though unless the meals be very far deed, the whole of the material of one meal has ed into the blood before the next meal is begun. hough the muscles, even when completely at rest, ng up oxygen and nutritive material, and giving onic acid and other waste products, they give out e in much more when they are at work. So also "secreting glands" as they are called, which we dy presently, such as the salivary glands, have of repose; it is at certain times only, as when s been taken, that they pour out any appreci- ntity of fluid. Hence though they are probably p material from the blood and storing it up in bstance even when they appear at rest, they take more and so become much more distinctly means to the blood, when they are actively pouring secretions.[1] In the case of the liver the loss to d is more constant, since the secretion of bile as see is continually going on, though greater at imes than at others; and the materials for the e to be provided by the blood. Some of the nts of the bile, however, pass back from the

ord "secretion" is used by physiologists in two senses. Pri- is used to denote the sum total of the processes by which a gan *forms* the fluid which it gives out; thus we say that the ands "secrete" saliva. But the fluid thus formed is itself as "a secretion." The word "excretion" is usually applied id which after its formation is useless and requires to be at id of. Thus we say that urine is an excretion which is se- formed) by the kidneys; and we speak of those secretory which get rid of waste as excretory organs.

intestines into the blood ; and so far the loss to the blo by the liver is temporary only.

Of all the gains to the blood perhaps the most con stant is that of oxygen, and of all the losses perhaps th most constant is that of carbonic acid ; but even thes vary a good deal at different times or under different ci cumstances.

Broadly speaking then the blood gains oxygen from th lungs, complex organic food materials from the alimentar canal, and various substances which we may speak of a waste substances from the several tissues ; and it loses o the one hand material which we may speak of as con structive material to the several tissues ; and on the othe hand material which passes away by the skin, lungs and kidney, as water, carbonic acid, urea, and saline bodies

And while it is continually receiving heat from th several tissues, it is also continually losing heat by th skin, lungs, and other free surfaces of the body.

The sources of loss and gain to the blood may be con veniently arranged in the following tabular form :—

SOURCES OF LOSS AND GAIN TO THE BLOOD.[1]

A. SOURCES OF LOSS :—

I. *Loss of Matter.*

1. The lungs : carbonic acid and water (fairl constant).
2. The kidneys : urea, water, salines (fairl constant).
3. The skin : water, salines (fairly constant).
4. The tissues : constructive material (variabl especially in the case of those tissue whose activity is intermittent, such as th muscles, many secreting glands, &c.).

[1] The learner must be careful not to confound the losses and gains the *blood* with the losses and gains of the *body* as a whole. The tw differ in much the same way as the internal commerce of a countr differs from its export and import trade.

Loss of Heat.

1. The skin.
2. The lungs.
3. The excretions by the kidney and the alimentary canal.

RCES OF GAIN :—

Gain of Matter.

1. The lungs : oxygen (fairly constant).
2. The alimentary canal : food (variable).
3. The tissues : products of their activity, waste matters (always going on but varying according to the activity of the several tissues).
4. The lymphatics : lymph (always going on but varying according to the activity of the several tissues).[1]

Gain of Heat.

1. The tissues generally, especially the more active ones, such as the muscles.
2. The blood itself, probably to a very small extent.

he Kidneys.—In the preceding Lesson we have ed the operation by which the lungs withdraw from ood much carbonic acid and water, and supply to the blood : we now proceed to the second source tinual loss, the KIDNEYS.

hese organs, there are two, placed at the back of the inal cavity, one on each side of the lumbar region spine. Each, though somewhat larger than the of a sheep, has a similar shape. The depressed, or e, side of the kidney is turned inwards, or towards ine ; and its convex side is directed outwards (Fig. From the middle of the concave side (called the

[1] gain from those lymphatics which are called lacteals, since it om the alimentary canal, varies much more.

hilus) of each kidney, a long tube with a small bore, the **Ureter** (*Ur.*), proceeds to the **Bladder** (*Bl.*).

The latter, situated in the pelvis, is an oval bag, the walls of which contain abundant unstriped muscular fibre, while it is lined, internally, by mucous membrane, and coated externally by a layer of the *peritoneum*, or double

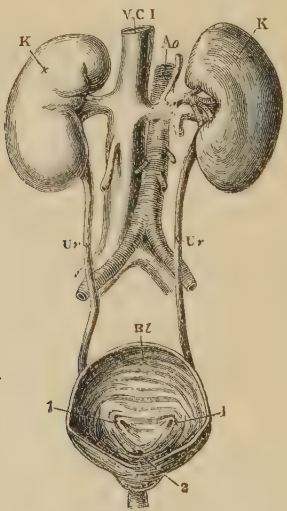


Fig. 50.

The kidneys (*K*); ureters (*Ur.*); with the aorta (*Ao.*); and vena cava inferior (*V.C.I.*); and the renal arteries and veins. *Bl.* is the bladder, the top of which is cut off so as to show the openings of the ureters (1, 1) and that of the urethra (2).

bag of serous membrane which has exactly the same relations to the cavity of the abdomen and the viscera contained in them as the pleuræ have to the thoracic cavity and the lungs. The ureters open side by side, but at some little distance from one another, on the posterior and inferior wall of the bladder (Fig. 50, 1, 1). Each

ureter is lined by an epithelium consisting of several layers of cells. Outside of these is a muscular coat made up of unstriated muscle-fibres, arranged in two layers and surrounded externally by some fibrous connective tissue. In front of the ureters is a single aperture which leads into the canal called the **Urethra** (Fig. 50, 2), by which the cavity of the bladder is placed in communication with the exterior of the body. The openings of the ureters enter the walls of the bladder obliquely, so that it is much more easy for the fluid to pass from the ureters into the bladder than for it to get the other way, from the bladder into the ureters.

Mechanically speaking, there is little obstacle to the free flow of fluid from the ureters into the bladder, and from the bladder into the urethra, and so outwards; but certain muscular fibres arranged circularly around the part called the "neck" of the bladder, where it joins the urethra, constitute what is termed a **sphincter**, and are usually, during life, in a state of contraction, so as to close the exit of the bladder, while the other muscular fibres of the organ are relaxed.

It is only at intervals that this state of matters is reversed; and the walls of the bladder contracting, while its sphincter relaxes, its contents, the **urine**, are discharged. But, though the expulsion of the secretion of the kidneys from the body is thus intermittent, the excretion itself is constant, and the urinary fluid flows, drop by drop, from the opening of the ureters into the bladder. Here it accumulates, until its quantity is sufficient to give rise to the uneasy sensations which compel its expulsion.

3. The Structure of a Kidney.—When a longitudinal section of a kidney is made (Fig. 51), the upper end of the ureter (*U*) seems to widen out into a basin-like cavity (*P*), which is called the **pelvis** of the kidney. Into this sundry conical elevations, called the **pyramids** (*Py*) project; and their summits present multitudes of minute

openings—the final terminations of the **tubules**, of which the thickness of the kidney is chiefly made up. If the tubules be traced from their openings towards the outer surface, they are found, at first, to lie parallel with one another in bundles, which radiate towards the surface, and subdivide as they go ; but at length they spread about irregularly, and become coiled and interlaced. From this

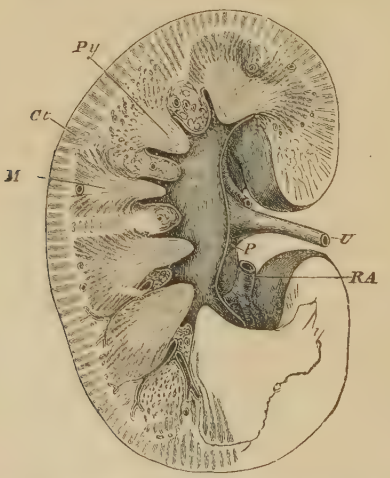


FIG. 51.—LONGITUDINAL SECTION OF THE HUMAN KIDNEY.

Ct, the cortical substance ; *M*, the medullary substance ; *P*, the pelvis of the kidney ; *U*, the ureter ; *R.A*, the renal artery ; *Py*, the pyramids.

circumstance, the middle part, or **medulla** (*medulla*, marrow) of the kidney looks different from the superficial part or **cortex** (*cortex*, bark) ; but, in addition, the cortical part is more abundantly supplied with vessels than the medullary, and hence has a darker aspect. Each tubule after a very devious course ultimately terminates in a dilatation (Fig. 52) called a **Malpighian capsule**.

Into the summit of each capsule, a small vessel (Figs. 52 and 53, *v.a*), one of the ultimate branches of the **renal artery**, which reaches the kidney at the concave side, with the ureters, and divides into branches which pass in between the pyramids (Fig. 51, *RA*), enters (driving the thin wall of the capsule before it), and immediately breaks up into a bunch of looped capillaries, called a **glomerulus** (Fig. 52 *gl*), which nearly fills the cavity of the capsule. The blood is carried away from this glomerulus

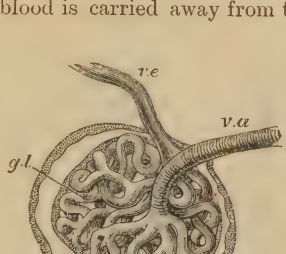


FIG. 52.—A MALPIGHIAN CAPSULE (HIGHLY MAGNIFIED).

v.a, small branch of renal artery entering the capsule, breaking up into the glomerulus, *g.l*, and finally joining again to form the vein, *v.e*.
c, the tubule; *a*, the epithelium over the glomerulus; *b*, the epithelium lining the capsule.

by a small vein or vessel (*ve*), which does not, at once, join with other veins into a larger venous trunk, but opens into the network of capillaries (Fig. 53) which surrounds the tubule, thus repeating the portal circulation on a small scale.

The course of the tubules is devious and peculiar. After leaving the capsule each tubule becomes twisted and is spoken of as **convoluted** (Fig. 54, II.). Passing towards the medulla, at first in a slightly **spiral** course, it proceeds straight down into the pyramid, where it bends

back upon itself and runs up again into the cortex. The loop thus formed is known as the **loop of Henle,**[1] and the two parts of which it is formed are called the **descending limb** and the **ascending limb** of the loop (Fig. 54, III. IV.).

Reaching the cortex once more the tubule becomes **zigzag** and then again **convoluted,** after which it

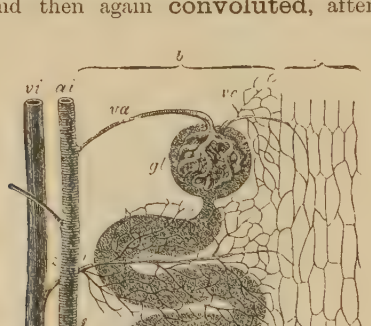


FIG. 53.—CIRCULATION IN THE KIDNEY.

ai, small branch of renal artery giving off the branch *va*, which enters glomerulus, issues as *ve*, and then breaks up into capillaries, which after surrounding the tubule find their way by *v* into *vi*, branch of the renal vein; *a*, capillaries around tubules in parts of the cortical substance where there are no glomeruli.

passes into a straight part or **collecting tubule,** which, leaving the cortex finally for the medulla and uniting with other similar collecting tubules, forms the discharging tubule which finally opens near the summit of a pyramid (Fig. 54, V.–IX.).

Each tubule is lined throughout by cells, the epithelium, and the cells differ in their characters in the several

[1] Who first described it.

parts of its course. The details of these differences are numerous and complicated, but the following statement includes all that is most essential. The cells in the convoluted, spiral and zigzag portions are, on the whole, large, very granular and striated, and both the

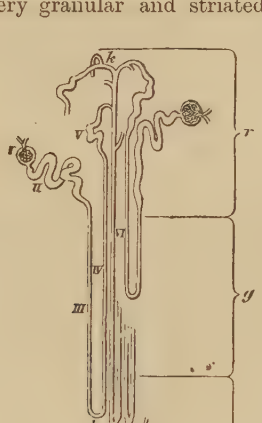


FIG. 54.—DIAGRAMMATIC VIEW OF THE COURSE OF THE TUBULES IN THE KIDNEY.

r, cortical portion answering to *Ct* in Fig. 51, *k* being close to the surface of the kidneys; *g*, *p*, medullary portion, *p* reaching to the summit of the pyramid.

IX, opening of tubule on the pyramid; *VIII*, *VII*, *VI*, the straight portion of the tubules; *V–II*, the twisted portion of the tubules; *I*, the Malpighian capsule.

cells and their nuclei stain readily and deeply. In the collecting tubules the cells are flattened, cubical, quite free from granules and do not stain readily. In the loop of Henle the cells of the descending limb resemble those in the collecting tubules in being flattened and

free from granules; the cells of the ascending limb, though small, are somewhat granular and often striated and thus present affinities to the cells of the convoluted tubules. These two chief types of cells are shown in Fig. 55.

The artery which supplies the kidney enters at the hilus and divides into branches which pass round the pelvis and proceed outwards between the pyramids. At

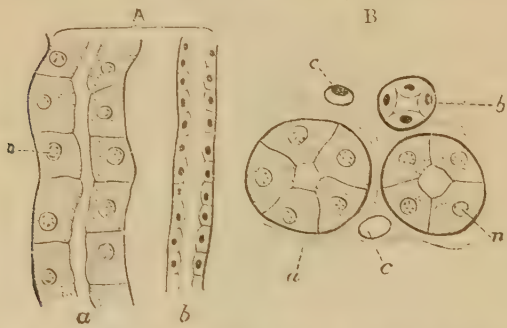


FIG. 55.—TYPES OF THE TWO CHIEF KINDS OF CELLS IN THE TUBULES OF THE KIDNEY.

A, tubules cut lengthwise; B, tubules cut across.
a, type of (secreting) cell lining the convoluted (spiral and zigzag) tubules; *b*, type of cells lining the conducting, collecting and discharging tubules; *n*, nuclei; *c*, in B, capillaries seen in section.

the junction of the medulla and cortex these branches spread out sideways and form arches. From these arches branches run (i) straight out to the surface of the kidney giving off smaller lateral branches, of which some pass to the capsules while others supply the capillary network round the tubules: (ii) down towards the pyramids, in whose substance they break up into capillaries. The veins also form arches at the junction of the cortex and medullæ, into which the blood flows from the capillaries,

and leave the kidney by a course parallel to that of the entering arteries.

4. The Composition of Urine and Chemistry of Urea.—The renal secretion is a clear yellowish fluid,

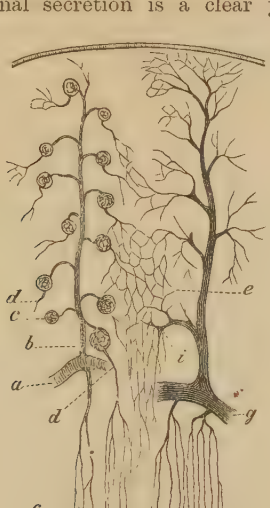


FIG. 56.—BLOOD VESSELS OF KIDNEY. (CADIAT)

a, part of arterial arch; *b*, interlobular artery; *c*, glomerulus; *d*, efferent vessel; *e*, capillaries of cortex; *f*, small arteries of medulla; *g*, venous arch; *h*, straight veins of medulla; *i*, interlobular vein.

whose specific gravity is not very different from that of blood-serum, being 1·020. In health it has a slightly acid reaction, due to the presence of acid sodium phosphate. It is composed chiefly of water, holding in solution (i) *organic substances*, of which the chief is **urea**,

with a very much smaller amount of **uric acid**. (ii) *Inorganic salts*, chiefly sodium chloride and sulphates and phosphates of sodium, potassium, calcium and magnesium. (iii) *Colouring matters*, of which but little is known. (iv) *Gases*, chiefly carbonic acid with a very small amount of nitrogen and still less oxygen.

An average healthy man excretes about 1,500 c.c. (50 ounces or $2\frac{1}{2}$ pints) of urine each day. In this are dissolved 33 grammes ($1\frac{1}{4}$ oz. or about 2 per cent.) of urea and not more than ·5 grammes (10 grains) of uric acid. The amount of salts is about half that of the urea, and of this the larger part consists of sodium chloride.

The quantity and composition of the urine vary greatly according to the time of day ; the temperature and moisture of the air ; the fasting or replete condition of the alimentary canal ; the nature of the food ; and the amount of fluid consumed.

The *quantity* depends on temperature and moisture of the air, because, as we shall see (p. 204), these determine the greater or less loss of water by the skin, and thus leave less or more to be excreted by the kidneys. The relationship of fluid consumed to the amount of urine excreted is obvious. The *composition* varies with the kind and amount of food, chiefly in respect of the amount of urea excreted, for the nitrogen in urea represents nearly all the nitrogen introduced into the body as proteids.

This relationship of the nitrogen in food to the nitrogen of urea confers upon urea its supreme importance as a constituent of urine. For the body cannot make good its nitrogenous waste from any source other than the nitrogen introduced into it in the form of proteids, and the nitrogen in this waste leaves the body again chiefly as urea, a very small part reappearing in the form of uric acid. Hence variations in the quantity of urea excreted thus become the measure of the amount of nitrogen turned over or "metabolised" in the body from time to time.

Urea is a white crystalline solid, very soluble in water, and composed of carbon, oxygen, hydrogen and nitrogen. Its chemical formula is $(NH_2)_2CO$, from which it is seen to contain rather more than 46 per cent. of nitrogen. It forms characteristic crystalline compounds with nitric acid and oxalic acid, which serve for its qualitative identification. When acted on by sodium hypobromite, urea is decomposed in such a way that all the carbon becomes carbon dioxide (carbonic acid gas) and the nitrogen is given off as a gas :

$$(NH_2)_2CO + 3NaBrO = N_2 + CO_2 + 2H_2O + 3NaBr.$$

This is an important reaction, since by measuring the nitrogen evolved the urea may be estimated quantitatively ; a method now very generally employed. When in solution, under the influence of a ferment sometimes secreted by the mucous membrane of the bladder, or of organisms from the air, urea takes up water and becomes ammonium carbonate ;

$$(NH_2)_2CO + 2H_2O = (NH_4)_2CO_3.$$

This accounts for the ammoniacal odour of stale urine.

Historically urea is interesting as being the first organic animal product prepared (synthetically) from inorganic sources.

5. The Secretion of Urine.—Many of the constituents of urine are present in blood. These appear in the urine dissolved in a large quantity of water, whereas many other substances also present in the blood do not, in a state of health, make their way into the urine. This suggests the idea that the kidney is a peculiar and delicate kind of filter which allows certain substances together with a large quantity of water to pass through it, but refuses to allow other substances to pass through. And when we come to study the minute structure of the kidney we find much to support this idea. Thus we saw that the surface of the glomerulus is, practically, free, or in direct

communication with the exterior by means of the cavity of the tubule ; and, further, that in each vessel of the glomerulus a thin stream of blood constantly flows, only separated from the cavity of the tubule by the capillary wall and the very delicate membrane covering the glomerulus. The Malpighian capsule may, in fact, be regarded as a funnel, and the membranous walls of the glomerulus as a piece of very delicate but *peculiar* filtering-paper, into which the blood is poured.

And indeed we have reason to think that a great deal of the water of urine together with certain of the constituents (the inorganic salts) is thus as it were filtered off by the Malpighian capsules. But it must be remembered that the process is after all very different from actual filtering through paper ; for filter paper will let everything pass through that is really dissolved, whereas the glomerulus, while letting some things through, refuses to admit others, even though completely dissolved.

Speaking of the process, with this caution, as one of filtration, it is obvious that the more full the glomerulus is of blood the more rapid will be the escape of urine. Hence we find that when blood flows freely to the kidney the urine is secreted freely, but that when the blood supply to the kidney is scanty the urine also is scanty. When the renal nerves going to the kidney are cut, the branches of the renal artery dilate, much blood goes into the kidney, the blood-pressure is raised in the glomeruli, and the flow of urine is copious. If the same nerves be stimulated, the arterial tubes are narrowed or constricted, less blood goes to the kidney, blood-pressure is reduced, and the flow of urine is scanty or may be stopped altogether.

While speaking of the process which takes place in the glomeruli as being thus largely a filtration, we must never forget that it is a very peculiar kind of filtration. And it acquires its peculiarities from the fact that, as in the case of lymph-formation (p. 122) the filtra-

n is taking place *across the substance of living*
gs.

We can now explain, in part at all events, how it is that
activity of the kidney is influenced by the state of the
n. The quantity of blood in the body, being about the
ne at all times, if a large quantity goes to the skin, as
warm weather and especially when the skin is active
perspiring, less will go to the kidney, and the
retion of urine will be small. On the other hand, if
blood be largely cut off from the skin, as in cold
ather, more blood will be thrown upon the kidney and
re urine will be secreted. Thus the skin and the
neys play into each other's hands in their efforts to get
of the superfluous water of the body.

But the whole of the urine is not thus secreted, through
ort of filtering process, by the Malpighian capsules.
e circulation in the kidney is peculiar, inasmuch as the
od coming from the glomeruli is not sent at once into
ein, but is carried into a second capillary network,
apped round the tubules. The tubules are lined,
has been stated, by epithelium cells, and these cells,
certain parts of the tubule, especially where these are
led, are what is called *secreting* cells. That is to say
y have the power, by some means which we do not at
esent fully understand, to take up from the blood,
ich is flowing in the capillaries wound round the
bules, or rather from the plasma which exudes from
se capillaries, and bathes the bases of the cells, certain
bstances, and to pour these substances into the cavity of
tubule.

And we have evidence that many of the most important
nstituents of the urine, such as urea, uric acid and
lers, are thus secreted by the epithelium cells of the
bules, and not simply filtered off by the Malpighian
sules.

We may give two striking facts in support of this view.
some animals the glomeruli of the kidney receive their

blood-supply by an artery, which is quite distinct from the vessel which takes blood to the tubules. When the artery supplying the glomeruli is tightly tied, no blood can go to the glomeruli, but *urea is still passed out* from the kidney and must come from the tubules. Again, a certain colouring matter when injected into the blood is excreted in the urine; this colouring matter can easily be tracked through the kidney and be *seen* to pass through the cells of the convoluted tubules and not through the walls of the glomerular blood-vessels.

The formation of urine is therefore a double process. A great deal of the water, with probably some of the more soluble inorganic salts, passes by the glomeruli, but the urea, the colouring matters and a great many other of the constituents, are thrown into the cavities of the tubules by a peculiar action of the epithelium cells.

6. The History of Urea.—Nitrogen enters the body as proteid food and, practically, all of it leaves the body again as urea. Somewhere or other, and by some means or other, the nitrogen while in transit is turned over from the proteids into urea. This change involves the whole nitrogenous metabolism[1] of the body and from its importance merits a short statement of the chief facts which throws some light on the question of where and how urea is formed.

In the first place the urea excreted in the urine is *not made in the kidney* out of some other (antecedent) substance. The activity of the kidney consists entirely in picking out ready-made urea from the blood which passes through it and discharging this urea into the channels of the tubules. Hence urea must be made in tissues other than the kidney and finds its way from these into the blood.

Nearly half the weight of the body is made up of

[1] The word metabolism (μεταβολή = change) is conveniently used to denote the sum total of those chemical changes which take place in living matter, and in virtue of which we speak of it as "living."

scular tissue, the muscles. These muscles are the seat ctive oxidation even when at rest, and this activity normously increased at times when they are contract-

There must therefore always be a considerable wear tear going on in them, and we must suppose that this ls to the formation of waste, of which some should tain nitrogen, since the muscles are chiefly built up itrogenous material. But this waste does not come of the muscles as ready-made urea, neither do we w as yet exactly in what form it does leave them. fact all we know is that the muscles give off nitrogenous ste, that this waste is presumably turned into urea ome other part of the body, and the urea picked out i excreted by the kidneys.

ut there is another organ in the body of great size importance, the liver (p. 207). This organ is the of many activities with which we shall deal later on, among these there is no doubt that the making of a out of other substances brought to it in the blood is the least important of them. We also know to a tain extent what one of these "other substances" is. ien we study digestion we shall see that one of products of digestion of proteids is a nitrogenous, stalline substance known as **leucin**. This is absorbed ough the walls of the intestines, carried to the liver in blood of the portal vein, and *converted into urea by the* r. Possibly the liver similarly converts other nitro- ous products, which it receives from the tissues, into a. But one thing is certain, a considerable portion of urea which is excreted by the kidneys is made in the r. Beyond this fact our knowledge of anything nite as to the mode of origin of urea in the body ery imperfect and incomplete.

The Structure of the Skin. Nails and Hairs.— t the skin is a source of continual loss to the blood be proved in various ways. If the whole body of a , or one of his limbs, be enclosed in a caoutchouc bag,

full of air, it will be found that this air undergoes changes which are similar in kind to those which take place in the air which is inspired into the lungs. That is to say, the air loses oxygen and gains carbonic acid ; it also receives a great quantity of watery vapour, which condenses upon the sides of the bag, and may be drawn off by a properly disposed pipe. Further there is a continual loss of heat taking place from the surface of the body. Of these the loss of watery vapour and of heat are of immense importance, for it is chiefly by means of variations in their amount from time to time that the temperature of the body is kept nearly constant. But before dealing with these activities of the skin we must understand the main facts as to its structure.

The skin consists of two parts, an outer layer or **epidermis**, resting on a deeper layer, the **dermis**. The skin as a whole is connected to the tissues it covers by a layer of loose fibrous connective tissue (see Fig. 28), called subcutaneous tissue. This often contains fat, and is the part which is cut through when an animal is skinned.

The dermis is made up of a dense feltwork of ordinary connective tissue fibres mixed with many elastic fibres and some connective tissue corpuscles (see Lesson XII.). The surface of the dermis is raised up into little hillocks or elevations known as the **papillæ**. Arteries enter the dermis and break up into capillaries which are very close set at its surface and in the papillæ ; thus the dermis is *extremely vascular*. Nerves also run into the dermis and passing outwards, form a branching layer of fibres at its junction with the epidermis, and from this layer extremely fine nerve fibrils pass out and between the lower cells of the epidermis. In some parts of the body, some of the branches of the nerves run up into the papillæ where they are connected with special nervous structures such as **tactile corpuscles** and **end bulbs**. But since these are of importance solely in connection with the

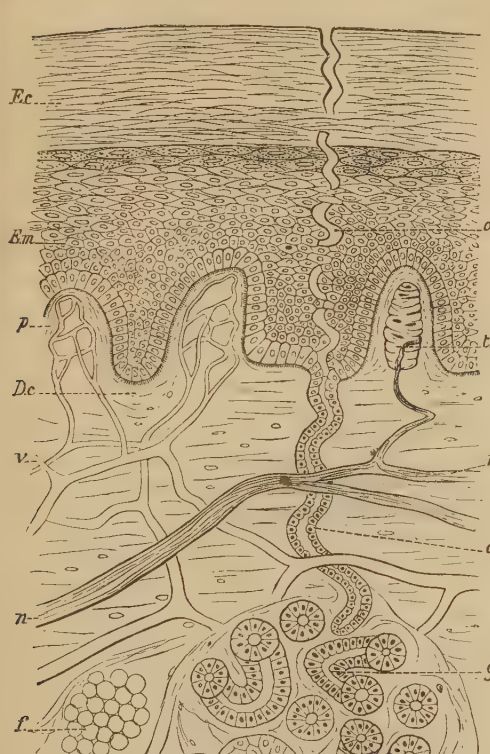


FIG. 57.—DIAGRAM TO SHOW THE STRUCTURE OF THE SKIN.

E.c, epidermis corneous part; *E.m*, epidermis Malpighian part; *D.c* onnective tissue of dermis; *p*, papilla; *gl*, sweat gland, the coils of the ibe cut across or lengthwise; *d*, its duct; *f*, fat; *v*, blood-vessels; nerve; *t.c*, tactile corpuscle.

functions of the skin as a sense-organ, they will be described later on (see Lesson VIII.).

The epidermis lies on the dermis and dips down into all its depressions. It is composed entirely of cells and has no blood-vessels.

The cells may be divided into two layers. Of these the innermost or **Malpighian layer** (Fig. 57, *Em.*) is made up of nucleated cells which are tall and columnar where they rest on the dermis, become more rounded and wrinkled as they pass outwards, and then flattened and granular. The outer layer of the epidermis or **corneous layer** (Fig. 57, *Ec.*) is made up of cells which, losing their nuclei become converted into flattened, thin scales, consisting of horny material. These are the cells which become so strongly developed on parts of the body subject to friction such as the hands and soles of the feet. They are always being shed from the surface of the skin, and their place is take by new cells passed up from the deeper layers of the epidermis (see also Lesson XII.).

All over the body the skin presents minute apertures, the ends of channels excavated in the epidermis, and each continuing the direction of a minute tube, usually about 80μ ($\frac{1}{300}$ of an inch) in diameter, and a quarter of an inch long, which is imbedded in the dermis. Each tube is lined with an epithelium continuous with the epidermis (Fig. 57, *d*). The tube sometimes divides, but, whether single or branched, its inner end or ends are blind, and coiled up into a sort of knot, interlaced with a meshwork of capillaries (Fig. 57, *gl*, and Fig. 58).

This coiled-up portion is called a sweat-gland, and the tube leading from it to the surface of the skin is its duct. The cells lining the duct are small and flat, those in the tube of the gland are larger and more columnar, and may be readily stained.

The blood in the capillaries of the gland is separated from the cavity of the sweat-gland only by the thin walls of the capillaries, that of the glandular tube, and its

pithelium, which, taken together, constitute but a very hin pellicle ; and the arrangement, though different in stail, is similar in principle to that which obtains in the dney. In the latter, the vessel makes a coil within the Malpighian capsule, which ends a tubule. Here the rspiratory tubule coils about, and among, the vessels.

FIG. 58.—COILED END OF A SWEAT-GLAND (Fig. 57, *gl.*), EPITHELIUM NOT SHOWN.

the coil ; *b*, the duct ; *c*, network of capillaries, inside which the duct gland lies.

n both cases the same result is arrived at—namely, the xposure of the blood to a large, relatively free, surface, n to which certain of its contents transude. In the weat-gland however there is no filtering apparatus like he Malpighian corpuscle of the kidney, and *the whole of he sweat appears to be secreted into the interior of the tube y the action of the epithelium cells which line it.*

The number of these glands varies in different parts of the body. They are fewest in the back and neck, where

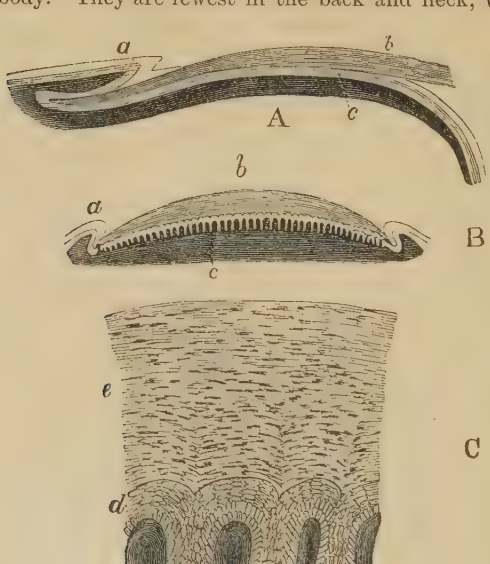


FIG. 59.

A, a longitudinal and vertical section of a nail; *a*, the fold at the base of the nail; *b*, the nail; *c*, the bed of the nail. The figure B is a transverse section of the same—*a*, a small lateral fold of the integument; *b*, nail; *c*, bed of the nail, with its ridges. The figure C is a highly-magnified view of a part of the foregoing—*c*, the ridges; *d*, the deep layers of epidermis; *e*, the horny scales coalesced into nail substance. (Figs. A and B magnified about 4 diameters; Fig. C magnified about 200 diameters.)

their number is not much more than 400 to a square inch. They are more numerous on the skin of the palm and

FIG. 60.—A HAIR IN ITS HAIR-SAC.

a, shaft of hair above the skin; *b*, cortical substance of the shaft, the medulla not being visible; *c*, newest portion of hair growing on the papilla (*i*); *d*, cuticle of hair; *e*, cavity of hair-sac; *f*, epidermis (and root-sheaths) of the hair-sac corresponding to that of the integument (*m*); *g*, division between dermis and epidermis; *h*, dermis of hair-sac corresponding to dermis of integument (*l*); *k*, mouths of sebaceous glands; *n*, horny epidermis of integument.

sole, where their apertures follow the ridges visible on the skin, and amount to between two and three thousand on

the square inch. At a rough estimate, the whole integument probably possesses not fewer than from two millions and a quarter to two millions and a half of these tubules, which therefore must possess a very great aggregate secreting power.

In certain regions of the skin the corneous cells of the epidermis are not at once thrown off in flakes, but are at first built up in definite structures known as **nails** and **hairs**, which grow by constant addition to the surfaces by which they adhere to the epidermis. In the case of the nails, the process of growth has no limit, and the nail is kept of one size simply by the wearing away of its oldest or free end. In the case of the hairs, on the contrary, the growth of each hair is limited, and when its term is reached the hair falls out and is replaced by a new hair.

Underneath each **nail** the deep or *dermic* layer of the integument is peculiarly modified to form the **bed of the nail**. It is very vascular, and raised up into numerous parallel ridges, like elongated papillæ (Fig. 59, B, C). The surfaces of all these are covered with growing epidermic cells, which, as they flatten and become converted into horn, form a solid continuous plate, the nail. At the hinder part of the bed of the nail the integument forms a deep fold, from the bottom of which, in like manner, new epidermic cells are added to the base of the nail, which is thus constrained to move forward.

The nail, thus constantly receiving additions from below and from behind, slides forwards over its bed, and projects beyond the end of the finger, where it is worn away or cut off.

A **hair**, like a nail, is composed of horny cells; but instead of being only partially sunk in a fold of the integument it is at first wholly enclosed in a kind of bag, the **hair-sac** or **follicle**, from the bottom of which a **papilla** (Fig. 60, *i*), which answers to a single ridge of the nail, arises. The hair is developed by the conversion into horn, and coalescence into a **shaft**, of the superficial epidermic

ells coating the papilla. These coalesced and cornified ells being continually replaced by new growths from elow, which undergo the same metamorphosis, the shaft f the hair is thrust out until it attains the full length atural to it. Its base then ceases to grow, and the old papilla and sac die away, but not before a new sac and papilla have been formed by budding from the sides of he old one. These give rise to a new hair. The shaft a hair of the head consists of a central pith, or **medullary** matter, of a loose and open texture, which metimes contains air; of a **cortical** substance sur-

IG. 61.—PART OF THE SHAFT OF A HAIR INCLOSED WITHIN ITS ROOT-SHEATHS AND TREATED WITH CAUSTIC SODA, WHICH HAS CAUSED THE SHAFT TO BECOME DISTORTED.

medulla; *b*, cortical substance; *c*, cuticle of the shaft; from *d* to *f*, the root-sheaths, in section. (Magnified about 200 diameters.)

ounding this, made up of coalesced elongated horny cells; nd of an outer **cuticle** composed of flat horny plates, rranged transversely round the shaft, so as to overlap ne another by their outer edges, like tiles on the roof of house. The superficial epidermic cells of the hair-sac lso coalesce by their edges, and become converted into **oot-sheaths**, which embrace the root of the hair, and sually come away with it when it is plucked out.

The sebaceous glands are small glands whose duct opens nto the follicle of a hair. They form a fatty secretion hich lubricates the hairs.

8. The Composition and Quantity of Sweat.—The sweat glands have the function of forming a fluid, the sweat, which is passed out on to the surface of the body. This fluid is composed chiefly of water containing a small amount (1–2 per cent.) of solid matter in solution, chiefly sodium chloride. In health, sweat contains *no appreciable* amount of urea.

In its normal state the sweat, as poured out from the proper sweat-glands, is alkaline; but ordinarily, as it collects upon the skin, it is mixed with the fatty secretion of the *sebaceous glands*, and then is frequently acid. In addition it contains scales of the external layers of the epidermis, which are constantly being shed.

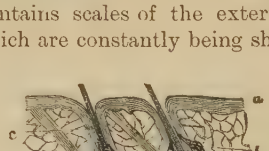


FIG. 62.—SECTION OF THE SKIN SHOWING THE ROOTS OF THE HAIRS AND THE SEBACEOUS GLANDS.

a, epidermis; *b*, muscle of *c* the hair sheath, on the left hand.

Under ordinary conditions the sweat is evaporated from the surface of the skin as fast as it is secreted; in this case it is frequently spoken of as *insensible* perspiration. But when violent exercise is taken, or under some kind of mental emotion, or when the body is exposed to a hot and moist atmosphere, the sweat is secreted faster than it evaporates: the perspiration then becomes *sensible*, that is it appears in the form of scattered drops on the surface of the body.

The quantity of sweat, or sensible perspiration, and also the total amount of both sensible and insensible perspiration, vary immensely, according to the tempera-

ure and other conditions of the air, and according to the state of the blood and of the nervous system. It is estimated that, as a general rule, the quantity of water excreted by the skin is about double that given out by the lungs in the same time.

The amount of matter which may be lost by perspiration under certain circumstances, is very remarkable. Heat and severe labour, combined, may reduce the weight of a man two or three pounds in an hour, by means of the cutaneous perspiration alone; and, as there is some reason to believe that the quantity of solid matter carried off from the blood does not diminish with the increase of the amount of the perspiration, the total amount of solids which are eliminated by profuse sweating may be considerable.

9. A Comparison of the Lungs, Kidneys, and Skin.—It will now be instructive to compare together in more detail than has been done in the first Lesson (p. 24), the three great organs—lungs, kidneys, and skin—which have been described.

In ultimate anatomical analysis, each of these organs consists of a moist animal membrane separating the blood from the atmosphere.

Water, carbonic acid, and solid matter pass out from the blood through the animal membrane in each organ, and constitute its secretion or excretion; but the three organs differ in the absolute and relative amounts of the constituents the escape of which they permit.

Taken by weight, water is the predominant excretion in all three; most solid matter is given off by the kidneys; most gaseous matter by the lungs.

The skin partakes of the nature of both lungs and kidneys, seeing that it absorbs oxygen and exhales carbonic acid and water, like the former, while it excretes organic and saline matter in solution, like the latter; but the skin is more closely related to the kidneys than to the lungs. Hence, as has been already said, when the

free action of the skin is interrupted, its work is usually thrown upon the kidneys, and *vice versa*. In hot weather, when the excretion by the skin increases, that of the kidneys diminishes, and the reverse is observed in cold weather.

This power of mutual substitution, however, only goes a little way; for if the kidneys be extirpated, or their functions much interfered with, death ensues, however active the skin may be. And, on the other hand, if the skin be covered with an impenetrable varnish, the temperature of the body rapidly falls, and death takes place, though the lungs and kidneys remain active.

10. The Secretion of Sweat and its Nervous Control.—In analysing the process by which the perspiration is eliminated from the body, it must be recollected, in the first place, that the skin, even if there were no glandular structures connected with it, would be in the position of a moderately thick, permeable membrane, interposed between a hot fluid, the blood, and the atmosphere. Even in hot climates the air is, usually, far from being completely saturated with watery vapour, and in temperate climates it ceases to be so saturated the moment it comes into contact with the skin, the temperature of which is, ordinarily, twenty or thirty degrees above its own.

A bladder exhibits no sensible pores; but if a bladder be filled with water and suspended in the air, the water will gradually ooze through the walls of the bladder, and disappear by evaporation. Now, in its relation to the blood, the skin is such a bladder full of hot fluid.

Thus, perspiration to a certain amount, must always be going on through the substance of the integument, but probably not to any great extent; though what the amount of this perspiration may be cannot be accurately ascertained, because it is entirely masked by the secretion from the sweat-glands.

When from any ordinary cause an increased formation

E sweat takes place, two things usually happen. The nall arteries which supply the capillary network rrounding the coiled tube of the sweat-gland dilate nd there is an increased flow of blood through these apillaries. At the same time the cells of the glands begin to our out an increased quantity of fluid, in other words they gin to secrete. The first of the above two results is rought about by a *lessening of the vaso-constrictor mpulses* which had previously been keeping the arteries nstricted (see p. 68). But what, on the other hand, is he cause of the simultaneously increased activity of the weat-glands? Do they simply secrete faster because of he increased supply of blood brought to them? Or is it ecause their cells are urged on to greater activity by pecial nervous impulses sent to them? The latter is the eal explanation of the increased activity of the cells, as hown by the following facts.

It is possible to obtain an increased secretion of sweat y the stimulation of nerves in parts of an animal's body rom which the blood supply has been previously cut off. gain, certain drugs may lead to sweating without at the ame time producing any vascular changes, and the same ffect is often observed in sweating which results from nental emotions and in the "cold sweats" of a disease uch as phthisis. The nerves which can thus make the ells of the sweat-glands become more active may be called **secretory nerves.** They appear to be connected with centre in the central nervous system, and by this means weating may be brought about reflexly, as when placing nustard in the mouth causes the face to sweat. The ossibility of such reflex stimulation of the sweat-glands cquires an extraordinary importance, as we shall see hen we come to consider the means by which the temerature of the body is regulated (p. 204).

The ideas we have thus arrived at as to the process of weat secretion hold good for all secreting glands; and e shall have to consider them again later on, when

dealing with certain of the salivary glands, in which this independence of secretion and blood-supply is much more strikingly shown (see Lesson VI.).

11. Animal Heat: its Production and Distribution.—It has been seen that heat is being constantly given off from the skin and from the air-passages; and everything that passes from the body carries away with it, in like manner, a certain quantity of heat. Furthermore, the surface of the body is much more exposed to cold than its interior. Nevertheless, the temperature of the body is in health maintained very evenly, at all times and in all parts, within the range of two degrees or even less on either side of 37° C. (98·6° Fahrenheit).

This is the result of three conditions:—the first, that heat is constantly being generated in the body; the second, that it is as constantly being distributed through the body; the third, that it is subject to incessant regulation as regards both loss and production.

Heat is generated whenever oxidation takes place. As we have seen, the tissues all over the body, muscle, brain-substance, gland cells and the like, are continually undergoing oxidation. The living substance of the tissue, built up out of the complex proteids, fats, and carbohydrates, and thus even still more complex than these, is, by means of the oxygen brought by the arterial blood, oxidised, and broken down into simpler more oxidised bodies, which are eventually reduced to urea, carbonic acid, and water. Wherever life is being manifested these oxidative changes are going on, more energetically in some places, in some tissues, and in some organs, than in others. Hence every capillary vessel and every extra-vascular islet of tissue is really a small fireplace in which heat is being evolved, in proportion to the activity of the chemical changes which are going on.

The chief seat of this heat production is undoubtedly in the muscles; for, as already pointed out, they make up about half the body-weight, and are carrying on an active

xidation even while at rest. This gives rise to heat, and hen a muscle enters into a state of contracting activity, he heat production becomes so rapid as to produce an ctual measurable rise of its temperature. After the uscles we may regard the liver as the next great heat-roducing organ of the body.

But as the vital activities of different parts of the ody, and of the whole body, at different times, are very ifferent; and as some parts of the body are so situated s to lose their heat by radiation and conduction much nore easily than others, the temperature of the body would be very unequal in its different parts, and at ifferent times, were it not for the arrangement by which he heat is distributed and regulated.

Whatever oxidation occurs in any part, raises the tem-erature of the blood which is in that part at the time, o a proportional extent. But this blood is swiftly hurried way into other regions of the body, and rapidly gives up ts excess heat to them. On the other hand, the blood vhich, by being carried to the vessels in the skin on the urface of the body begins to have its temperature lowered y evaporation, radiation, and conduction, is hurried way, before it has time to get thoroughly cooled, into the leeper organs; and in them it becomes warm by contact, s well as by the oxidating processes there going on. Thus the blood-vessels and their contents may be ompared to a system of hot-water pipes, through which he warm water is kept constantly circulating by a pump; vhile it is heated not by a great central boiler as usual, ut by a multitude of minute gas jets, disposed beneath he pipes, not evenly, but more here and fewer there. It s obvious that, however much greater might be the heat pplied to one part of the system of pipes than to another, he general temperature of the water would be even hroughout, if it were kept moving with sufficient quick-ess by the pump. In this way, then, the temperature of he body is kept *uniform* in its several parts.

12. Regulation of Body-temperature by Altered Loss of Heat.—If a system such as we have just imagined were entirely composed of closed pipes, the temperature of the water might be raised to any extent by the gas jets. On the other hand, it might be kept down to any required degree by causing a larger, or smaller, portion of the pipes to be wetted with water, which should be able to evaporate freely—as, for example, by wrapping them in wet cloths. And the greater the quantity of water thus evaporated, the lower would be the temperature of the whole apparatus.

Now, the regulation of the temperature of the human body is chiefly effected on this principle. The vessels are closed pipes, but a great number of them are inclosed in the skin and in the mucous membrane of the air-passages, which are, in a physical sense, wet cloths freely exposed to the air. It is the evaporation from these which exercises a more important influence than any other condition upon the regulation of the temperature of the blood, and, consequently, of the body.

But, as a further nicety of adjustment, the wetness of the regulator is itself determined, through the aid of the nervous system, by the temperature of the body. The sweat-glands, as we have seen, may be made to secrete by impulses reaching them along certain nerves coming from a centre in the central nervous system. This centre is itself connected by other nerves with the skin, and the ends of these cutaneous nerves are so constituted that they are stimulated by heat applied to the skin. When the body is exposed to a high temperature (and the same occurs when a part only of the body is heated), these cutaneous nerves convey impulses to the central nervous system, from which other impulses are then sent out along the secretory nerves to the sweat-glands and cause them to pour forth a copious secretion on to the skin; and when the temperature falls, the glands cease to act. Moreover, in this work of secreting sweat, the sweat-

ands are assisted by corresponding changes in the blood-ssels of the skin. It has been stated (see p. 68) that e small arteries of the body may be sometimes narrowed constricted, and sometimes widened or dilated. Now e condition of the small arteries, whether they are nstricted or dilated, depends, as we have also seen, on the action of certain nerves (vaso-motor nerves). d it appears that when the body is exposed to a high mperature these nerves are so affected as to lead to a lation of small arteries of the skin; but when these e dilated the capillaries and small veins in which they d become much fuller of blood, and from these filled d swollen capillaries much more nutritive matter passes rough the capillary walls to the sweat-glands, so that ese have more abundant material from which to manu-cture sweat. On the other hand, when the body is wered in temperature the vaso-motor nerves are so fected that the small arteries of the skin are constricted; nce less blood enters the capillaries of the skin, and ss material is brought to the sweat-glands.

Thus when the temperature is raised two things happen, oth brought about by the nervous system. In the first ace, the arteries of the skin are widened so that a much rger proportion of the total blood of the body is carried the surface of the skin and there becomes cooled: and, condly, this cooling process is greatly helped by the in-eased evaporation resulting from the increased action of e sweat-glands, whose activity is further favoured by the resence in the skin of so much blood. Conversely when e temperature is lowered, less of the blood is brought to e skin, and more of the blood circulates through the eeper, hotter parts of the body, and the sweat-glands ase their work (this quiescence of theirs being in turn voured by the lessened blood-supply); hence the evapo-tion is largely diminished, and thus the blood is much ss cooled.

Hence it is that, so long as the surface of the body per-

spires freely, and the air-passages are abundantly moist, a man may remain with impunity, for a considerable time, in an oven in which meat is being cooked. The heat of the air is expended in converting this superabundant perspiration into vapour, and the temperature of the man's blood is hardly raised.

13. **Regulation of Body-temperature by Altered Production of Heat.**—The temperature of the body is kept constant by that carefully adjusted variation in loss of heat from its surface which has been described in the preceding section. But now we may point out that there is another way by which this constancy *might* be attained, namely by *altering the production of heat* taking place in the body, in correspondence to the changes of the surrounding temperature ; just as the temperature of a room may be regulated by putting out or increasing the fire as well as by opening or closing its windows. The question thus raised is very interesting, but it is also very abstruse, and we must not do more than just touch upon it.

All oxidation in the body involves the consumption of oxygen, the production of carbonic acid and the generation of an exactly corresponding quantity of heat We may therefore take the difference in the amount of oxygen used up (and of carbonic acid produced) at different times as a measure of the amount of heat being produced in the body during the same periods. Working in this way it is found that when a warm-blooded animal is exposed to cold, as when it is put into a chamber which is cooled, it uses up more oxygen and gives off more carbonic acid than when put into a warm chamber. But this can only mean that in the cooler surroundings the animal makes more heat than when the surroundings are warm. Again we may point out, as tending to the same conclusions, that our desire for food is greater, on the whole, in the cooler winter time than in the warmer summer ; and all food is oxidised in the body and during this oxidation gives rise to heat. Thus there are reasons for supposing

within certain limits altered production of heat may some part in keeping the temperature of the body nstant.

All the functions of the body which we have so far died have been seen to be under the guidance of nervous pulses. We may therefore suppose that the production heat will be no exception to the rule, and indeed there reasons, based largely on experiment and partly on phenomena of certain diseases, which justify this view. ore than this we must not say.

14. The Temperature of Fever.—The condition to hich the name of fever is given is characterised essen-lly by the temperature of the body being higher than is ual in health. Thus it may rise to as much as 41° C. 05·8° F.) or occasionally even above this point, and there as been much dispute as to how this high temperature ises. By many it is regarded simply as the outcome of disturbance of the mechanism by which heat is lost to e body, some diminution in loss of heat leading naturally a rise of temperature; and probably, this is the most mmon cause of the rise of temperature. But on the her hand direct measurement shows that a fevered erson often *gives off more heat than usual* and at the same me uses up more oxygen and produces more carbonic id and urea than is usual. In such cases there is no ubt that the abnormally high temperature is largely due an over-production of heat.

15. The Liver.—The liver is a constant source both of ss, and, in a sense, of gain, to the blood which passes rough it. It gives rise to loss, because it secretes a culiar fluid, the **bile**, from the blood, and throws that id into the intestine. It is also in another way a urce of loss because it elaborates from the blood passing rough it a substance called **glycogen**, which is stored sometimes in large, sometimes in small, quantities in e cells of the liver. This latter loss, however, is only mporary, and may be sooner or later converted into a

gain, for this glycogen very readily passes into sugar, and either in that form or in some other way is carried off by the blood. In this respect, therefore, there is a gain to the blood of kind or quality though not of quantity of material.

The liver is the largest glandular organ in the body, ordinarily weighing about 1,400–1,700 grammes (fifty or sixty ounces). It is a broad, dark, red-coloured organ, which lies on the right side of the body, immediately below

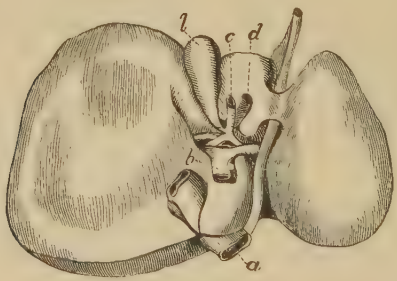


FIG. 63.—THE LIVER TURNED UP AND VIEWED FROM BELOW.

a, vena cava; *b*, vena portæ; *c*, bile duct; *d*, hepatic artery; *l*, gall-bladder. The termination of the hepatic vein in the vena cava is not seen, being covered by the piece of the vena cava.

the diaphragm, with which its upper surface is in contact, while its lower surface touches the intestines and the right kidney.

The liver is invested by a coat of peritoneum, which keeps it in place. It is flattened from above downwards and convex and smooth above, where it fits into the concavity of the lower surface of the diaphragm. Flat and irregular below (Fig. 63), it is thick behind, but ends in a thin edge in front.

Viewed from below, as in Fig. 63, the **inferior vena**

:ava, *a*, is seen to traverse a notch in the hinder edge of the liver as it passes from the abdomen to the thorax. At *b* the trunk of the **vena portæ** is observed dividing into the chief branches which enter into, and ramify through, the substance of the organ. At *d*, the **hepatic artery**, coming almost directly from the aorta, similarly divides, enters the liver, and ramifies through it. At *c* is the single trunk of the duct, called the **hepatic duct**, which conveys away the bile brought to it by its right and left branches from the liver. Opening into the hepatic duct is seen the duct of a large oval sac, *l*, the **gall-bladder**. The duct is smaller than the artery, and the artery than the portal vein.

The liver consists of two chief **lobes** of which the right is much larger than the left. Externally the lobes are covered with a layer of connective tissue forming its **capsule**, and a quantity of connective tissue forms a thick sheath for the vena portæ, hepatic artery and bile-duct, as these plunge into the liver. This sheath accompanies the vessels as they ramify into the liver and finally forms a number of partitions, continuous with the capsule on the outside, which divide each lobe into a very large number of smaller divisions called **lobules**. These partitions are much thicker and more conspicuous in some animals, such as the pig, than they are in others, such as the rabbit; in the former it is very easy to see on the outside of the liver the outlines of the lobules; in the latter it is not so easy. The lobules are about $\frac{1}{10}$ of an inch in diameter and are thus visible to the naked eye. Each lobule is made up of a mass of cells, the **hepatic cells**, which lie in the meshes of a close-set network of blood capillaries. These capillaries radiate from a small blood-vessel which runs down the centre of each lobule towards its base; this central blood-vessel is called the **intralobular vein** (Fig. 64, *A*, *H.V.*), and, passing out of the lobule at its base, runs into a branch of that great vein, the **hepatic vein**, which carries the blood away from the

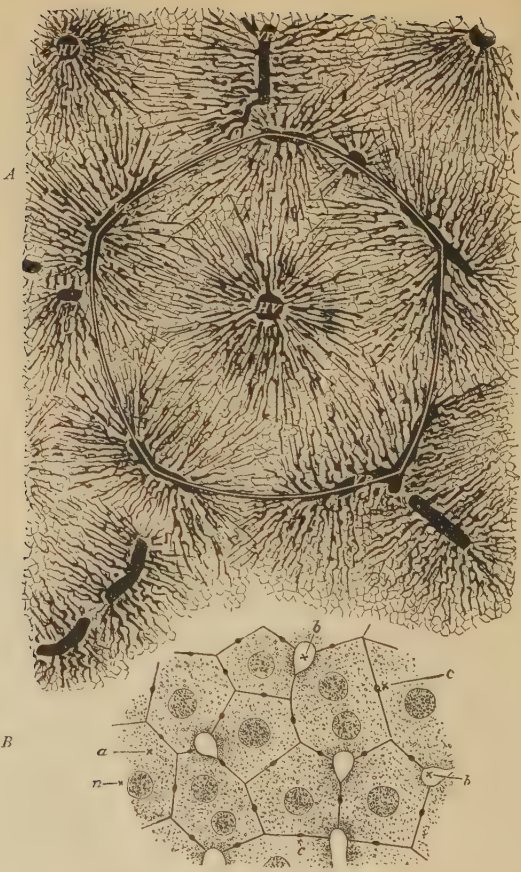


FIG. 64.

A. Section of partially injected liver magnified. The artificial white line is introduced to mark the limits of a lobule. *V.P*, branches of portal vein breaking up into capillaries, which run towards the centre of the lobule, and join *H.V*. the intralobular branch of the hepatic vein. The outline of the liver cells are seen as a fine network of lines throughout the whole lobule.

B. Portion of lobule very highly magnified. *a*, liver cell with *n*, nucleus (two are often present); *b*, capillaries cut across; *c*, minute biliary passages between the cells, injected with colouring matter.

ver. In this way each lobule comes to be seated by its ase on a branch of the hepatic vein (Fig. 65, *H.V.*).

If the branches of the hepatic artery, the portal vein, nd the bile duct be traced into the substance of the liver, hey will be found to accompany one another, and to

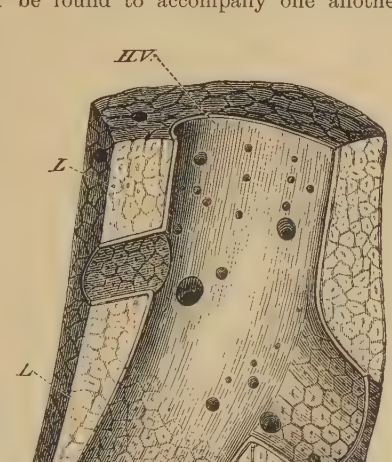


FIG. 65.—A SECTION OF PART OF THE LIVER TO SHOW *H.V.*, a branch of the hepatic vein, with *L*, the lobules or acini of the iver, seated upon its walls, and sending their intralobular veins into it.

branch out and subdivide, becoming smaller and smaller. At length the ultimate branches of the portal vein (Fig. 64, *V.P.*) reach the outer surfaces of the lobules, and passing round and between them are known as the **interlobular veins.** These veins pour their blood into the network of capillaries which permeate each lobule. The branches

of the hepatic artery follow a course parallel to that of the portal vein and finally, reaching the surface of a lobule, pour the blood they carry into the lobular capillaries.

Thus the venous blood of the portal vein and the arterial blood of the hepatic artery reach the surfaces of the lobules by the ultimate branches of that vein and artery, become mixed in the capillaries of each lobule, and are carried off by its *intralobular* veinlet, which pours its contents into one of the branches of the hepatic vein. These branches, joining together, form larger and larger trunks, which at length reach the hinder margin of the liver, and finally open into the *vena cava inferior*, where it passes upwards in contact with that part of the organ.

Thus the blood with which the liver is supplied is a mixture of arterial and venous blood : the former brought by the hepatic artery directly from the aorta, the latter by the portal vein from the capillaries of the stomach, intestines, pancreas, and spleen.

In the lobules themselves all the meshes of the blood-vessels are occupied by the *liver cells*, or *hepatic cells*. These are many-sided minute bodies, each about 25μ ($\frac{1}{1000}$th of an inch) in diameter, possessing a nucleus in its interior, and frequently having larger and smaller granules of fatty matter distributed through its substance (Fig. 64, *B*, *a*). It is in the liver cells that the active powers of the liver reside.

The smaller branches of the hepatic duct, lined by an epithelium, which is continuous with that of the main duct, and thence with that of the intestines, into which the main duct opens, may be traced to the very surface of the lobules, where they seem to end abruptly (Fig. 66). But, upon closer examination, it is found that they communicate with a network of minute passages passing between the hepatic cells, and traversing the lobule in the intervals left by the capillaries (Fig. 64, *B*, *c*). These

minute passages are the **bile canaliculi.** The bile manufactured by the hepatic cells finds its way first into these minute passages, and from them into the ducts.

16. The Work of the Liver. Its Glycogenic Function.—The work of the liver, and this, as has been said, is carried out by the hepatic cells, may be considered as consisting of two kinds.

On the one hand, the hepatic cells are continually en-

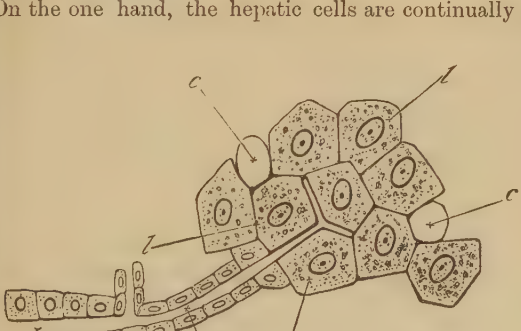


FIG. 66.—TERMINATION OF BILE DUCT AT EDGE OF LOBULE (SOMEWHAT DIAGRAMMATIC).

b, small bile duct, becoming still smaller at *b'*, the low, flat epithelium at last suddenly changing into the hepatic cells, *l*, the channel of the bile duct being continued as small passages between the latter. *c*, capillary blood-vessel cut across.

gaged in the manufacture of a complex fluid called bile, which they pour into the minute passages spoken of above, and thence into the branches of the hepatic duct; whence it flows through the duct itself into the intestines, or, when digestion is not going on and the opening of the duct into the intestine is closed, back to the gall-bladder. The materials for this bile are supplied to the

hepatic cells by the blood; hence the secretion of the bile constitutes a loss to the blood.

The total quantity of bile secreted in the twenty-four hours varies, but probably amounts to not less than from two to three pounds. It is a golden yellow, slightly alkaline fluid, of extremely bitter taste, consisting of water with from 15 per cent. to half that quantity of solid matter in solution. We shall deal with the composition of bile and the nature of its constituents when we come to speak of it in connection with digestion. For the present we may say that its colour is due to **bile-pigments**; that it contains certain compounds of sodium with organic acids called **bile-salts**; a remarkable crystalline substance called **cholesterin**; and some inorganic **salts**.

Of these constituents of the bile the essential substances, the bile acids and the colouring matter, are not discoverable in blood which enters the liver; they must therefore be formed in the hepatic cells. How they are exactly formed we do not at present clearly know. The material of which they are composed is brought to the hepatic cells by the blood, but the exact condition of that material—whether, for instance, the blood brings something very like the bile acids, and only needing a slight change to be converted into bile acids; or whether the hepatic cells manufacture the bile acids from the beginning, as it were, out of the common material which the blood brings to the liver as to all other tissues and organs—is not as yet quite determined. There is however but little doubt that the pigment of bile is in some way made out of the hæmoglobin of the red blood-corpuscles. The saline matters and cholesterin, on the other hand, appear to be present in the blood of the portal vein, and may therefore, like the water, be simply taken up by the cells from the blood, and passed on to the bile ducts.

Thus the bile is a continual loss to the blood. But,

sides forming bile, the hepatic cells are concerned in her labours, the result of which can hardly be considered either as a loss or as a gain, since these labours imply consist in manufacturing from the blood and storing up in the hepatic cells substances which, sooner or later, are returned, generally in a changed condition, back into the blood.

As we shall presently see, the portal blood is, after a meal, heavily laden with substances, the result of the digestive changes in the alimentary canal. When these substances, carried along in the portal blood, reach the hepatic cells, in the meshes of the lobules, some of them appear to be taken up by those cells and to be stored up in them in a changed condition. In fact, the products of digestion passing along the portal veins suffer (in the liver) a further change, which has been called a secondary digestion. Thus the liver produces a powerful effect on the quality of the blood passing through it, so that the blood in the hepatic vein is very different, especially after a meal, from the blood in the portal vein.

The changes thus effected by the hepatic cells are probably very numerous, but they have not been fully worked out, except in one particular case, which is very interesting and deserves special attention.

It is found that the liver of an animal which has been well and regularly fed, when examined immediately after death, contains a considerable quantity of a substance which is very closely allied to starch, consisting of carbon, hydrogen, and oxygen in proportions the same as in starch. This substance, which may by proper methods be extracted and preserved as a white powder, is in fact an **animal starch**, and is called **glycogen**. As we shall see, common starch is readily changed by certain agents into grape-sugar, or dextrose, as it should be called; and this glycogen is similarly converted with ease into dextrose. Indeed, if the liver of such an animal as the above,

instead of being examined immediately after death, be left in the body, or be placed on one side after removal from the body for some hours before it is examined, a great deal of the glycogen will have disappeared, a quantity of dextrose having taken its place. There seems to be present in the liver some agent capable of converting the glycogen into dextrose, and this change is particularly apt to take place if the liver is kept at blood-heat or near that temperature.

Now if, instead of the liver of a well-fed animal, the liver of an animal which has been starved for several days be examined in the same way, very little glycogen indeed will be found in it, and when this liver is left exposed to warmth for some time very little dextrose is found. That is to say, the liver has, in the first case, formed the glycogen and stored it up in itself, out of the food brought to it by the portal blood : in the second case, no food has been brought to the liver from the alimentary canal, no glycogen has been formed, and none stored up. If the liver in the first case be examined microscopically with certain precautions, the glycogen may be seen stored up in the hepatic cells ; in the second case little or none can be seen.

The kind of food which best promotes the storing up of glycogen in the liver is one containing starch or sugar ; but some glycogen will make its appearance even when an animal is fed on an exclusively proteid diet, though not nearly so much as when starch or sugar is given.

It would appear, then, that the hepatic cells can manufacture and store up in themselves the substance glycogen, being able to make it out of even proteid matter, but more easily making it out of sugar ; for, as we shall see, all the starch which is eaten as food is converted into sugar in the alimentary canal, and reaches the liver as sugar.

There are reasons for thinking that the glycogen, thus deposited and stored up in the liver, is converted into sugar little by little as it is wanted, poured into the

patic vein, and thus distributed over the body. So that may regard this remarkable formation of glycogen in liver as an act by which the blood, when it is over-h in sugar, as after a meal, stores it up or deposits it in liver as glycogen ; and then, in the intervals between ls, the liver deals out the stored-up material as sugar k again in driblets to the blood. The loss to the blood, refore, is temporary—no more a real loss than when a n deposits at his banker's some money which he has eived until he has need to spend it.

This story of glycogen, important in itself, is also use-l as indicating other possible effects of a similar nature ich the hepatic cells may bring about on the blood, as is passing in the meshes of the lobules of the liver from e veinlets of the portal to the veinlets of the hepatic vein.

17. The Spleen.—The spleen lies in the abdominal vity, slightly below and towards the left side of the omach and immediately to the left of the tail of the ncreas (Fig. 67). It is an elongated, flattened, red dy, abundantly supplied with blood by an artery called e **splenic artery**, which proceeds almost directly from e aorta. The blood which has traversed the spleen is llected by the **splenic vein**, and is carried by it to e portal vein, and so to the liver. The spleen is vered by a capsular sheath of connective tissue mixed ith a good deal of elastic tissue and in some animals great deal of unstriated muscle fibres. Somewhat in ne same way as in a lymphatic gland (p. 89) this cap-ule sends branching projections or **trabeculæ** inwards hich divide the organ up into a number of irregular paces, and these spaces are filled with a mass of spongy ssue called the **spleen-pulp**. The pulp is traversed y a network of branching cells whose processes are mewhat flattened and join on to the processes of eighbouring cells. The meshes of this network are ccupied by red blood corpuscles, by colourless cor-uscles closely similar to those of lymph, and by other

kinds of cells peculiar to the spleen. Some of the latter resemble a colourless corpuscle of blood, in that they can perform amœboid movements, but they are larger and contain in their substance red corpuscles in various stages of disintegration.

A section of the spleen shows a dark red spongy mass dotted over with minute whitish spots. Each of these last is the section of one of the spheroidal bodies called

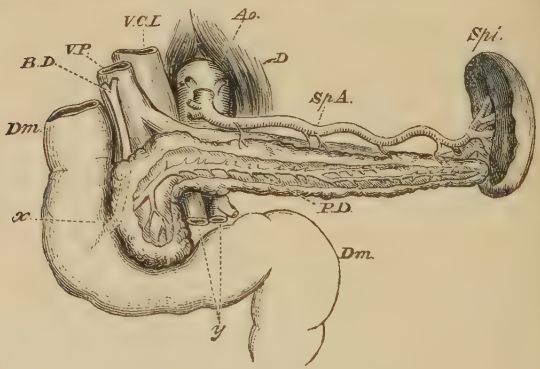


FIG. 67.

The spleen (*Spl.*) with the splenic artery (*Sp.A.*). Below this is seen the splenic vein running to help to form the vena portæ (*V.P.*). *Ao*, the aorta; *D*, a pillar of the diaphragm; *P.D.* the pancreatic duct exposed by dissection in the substance of the pancreas; *Dm*, the duodenum; *B.D*, the biliary duct uniting with the pancreatic duct into the common duct, *x*; *y*, the intestinal vessels.

corpuscles of the spleen, or **Malpighian corpuscles**, which are scattered through its substance. These corpuscles consist of little masses of lymphoid or adenoid tissue, very similar to that found in the lymphatic glands (p. 90), which surround the smaller branches of the arteries. They are crowded with leucocytes, and hence they stand out as white specks against the dark red pulp of the spleen.

The smallest branches of the arteries which carry blood

to the spleen, open into the network of the spleen-pulp, that the blood flows into and through this network; is then gathered up again into the ends of tiny veins, hich similarly open into the spleen-pulp, and carry the lood away into the splenic vein.

We are still very much in the dark as to the functions the spleen; they are without doubt of some import-ce; but on the other hand the spleen may be perman-tly removed from the body without producing any vious derangement of its working.

The elasticity of the splenic tissue allows the organ to readily distended with blood, and enables it to return its former size after distension. It appears to change dimensions with the state of the abdominal viscera, taining its largest size about six hours after a full meal, d falling to its minimum bulk six or seven hours later, no further supply of food be taken.

The blood of the splenic vein is found to contain pro-rtionally fewer red corpuscles, but more colourless rpuscles, than in the splenic artery; and it has been pposed that the spleen is one of those parts of the conomy in which, on the one hand, colourless corpuscles the blood are produced, and, on the other, red corpuscles ie and are broken up.

18. The Thymus Gland.—This is an organ which lies ver the trachea, in the lower part of the neck and ehind the sternum at the base of the heart. It is con-picuous at birth but soon begins to waste away, and in he adult is replaced by a small amount of connective ssue and fat. In structure it somewhat resembles a ymphatic gland; thus it has an external capsule from hich trabeculæ pass inwards and divide it up into regular ompartments or follicles. These follicles are filled with network of lymphatic connective tissue which is crowded ith leucocytes.

Nothing very definite is known of the function or use f this gland.

19. The Thyroid Body or Gland.—This organ consists of two lobes, one lying each side of the trachea just below the larynx and joined across the trachea by a connecting strip of its own tissue. Each lobe is covered with a capsule of connective tissue from which branches pass inwards and divide the interior into rounded spaces or alveoli. Each alveolus is lined by a layer of cubical cells so as to leave a large central space; this space in each alveolus is filled with a clear, viscid, often semi-solid, fluid. The viscidity of this fluid is due to the presence in it of a substance which in some respects is like the mucin of mucus.

The thyroid gland seems to have a good deal to do with the nutrition of the body. When diseased in man, it often leads to nutritive disorders, strikingly manifest in the skin, but also involving other organs and tissues, especially perhaps the nervous system and thus leading to nervous troubles. Occasionally the degenerations of the tissues take on the form of a change into a mucin-like substance. These troubles may be largely mitigated by administering an extract of the fresh gland or by eating the fresh gland-substance. Goitre is an enlargement of the thyroid, and cretinism, a peculiar form of idiocy common in some places, is associated with its diseased condition.

20. The Suprarenal Bodies.—The suprarenal bodies are two in number, are placed on the upper edge of each kidney. They are enveloped in an outer coat or capsule of connective tissue from which partitions pass into their interior. In this way each suprarenal is divided up into compartments. In the outer or *cortical* part the compartments are long and narrow, and placed with their long axis at right angles to the surface of the organ. In the centre or *medullary* portion the connective tissue forms a somewhat coarse network. The elongated spaces in the cortex are filled with large angular cells, placed in rounded groups immediately next to the capsule, but arranged

re in columns towards the central parts of the com-rtments. The cells which fill the spaces of the medullary work are of irregular shape and usually branched. ese cells contain some peculiar substance, of which but le is known beyond the fact that it gives a dark blue or en colour with ferric chloride, and a bright red colour treatment with oxidising agents.

The functions of the suprarenal bodies are important, hough, as yet, but little understood. When they are th removed from an animal, death speedily ensues, ac-npanied chiefly by a nutritional upset of the skeletal scles. When diseased in man, a similar defect is served in the muscles, together with nervous weakness d a characteristic "bronzing" or colouration of the n. Probably, as in the case of the thyroid gland, in-tion of extracts of the suprarenals may be found to tigate the symptoms which result from their being seased.

Extracts of the *medulla* when injected into the circula-n have an extremely marked action in causing a rise of od pressure. This is brought about by an extensive nstriction of the minute blood-vessels (arterioles) of the dy, and is due to the presence in the extract of a ystalline substance known as "adrenalin."

LESSON VI

THE FUNCTION OF ALIMENTATION

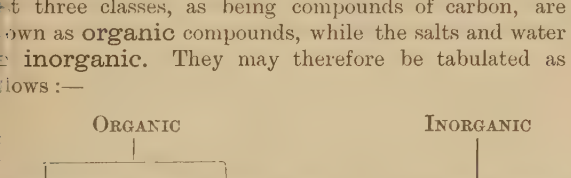
Part I.—Digestion and Absorption

1. Waste made good by Food.—We explained in the first Lesson that a living active man is always expending energy in the form of the mechanical (muscular) work he performs and of the heat he gives off by his skin and lungs. Further, we pointed out that the source from which the energy is derived lies in that constant oxidational breaking down of the tissues which results from their being supplied with oxygen, introduced into the body by the lungs. And further, it was shown that the above processes result in a waste of substance corresponding exactly to the amount of energy expended. If the man's activity is to continue from day to day, this continual waste of substance must be made good. Now the only channel, except the lungs, by which altogether new material is introduced into the body, is the alimentary canal, and we may use the word alimentation to denote the sum total of its operations in this connection. These fall naturally under three heads, viz. the *introduction* of food as new material; the reduction of this food by *digestion* to a condition such that it can pass through the delicate structures which form the walls of the vessels of the alimentary canal; and *absorption*, or the processes by which the digested material is passed from the cavity of the canal into the blood-vessels and lymphatics by

ich it is then distributed over the body. We may refore most suitably begin by learning something of nature and composition of that "new material" which introduce into the body as food.

2. **Food and Food-stuffs.**—Every one is familiar with meaning of the term **food**, as exemplified by bread, at, potatoes, milk, etc. None of these substances, wever, is made up of one kind of material; but when alysed it is found that they all consist of varying ounts of a few substances, and to these the name of od-stuffs is given.

Food-stuffs are classified under four heads, (1) **Proids**, (2) **Fats**, (3) **Carbohydrates**, (4) **Salts** ineral matter) and **Water**. They may further be ided into two distinct groups:—the **nitrogenous** and **non-nitrogenous**. The proteids alone contain rogen and thus form one group by themselves; the er food-stuffs are all non-nitrogenous. Further, the t three classes, as being compounds of carbon, are own as **organic** compounds, while the salts and water **inorganic**. They may therefore be tabulated as lows:—



A. Nitrogenous Food-Stuffs.

Proteids.—These are composed of the four elements rbon, oxygen, hydrogen and nitrogen united with all amounts of sulphur (see p. 108). Under this ad come the **albumin** of the white of egg, and od-serum; the **casein** of milk and cheese; the

gluton of flour and other cereals; the **myosin** of lean meat (muscle); the **globulins** of blood and of the yolk of an egg and the **fibrin** of blood.

Gelatin, the basis of connective tissue fibres, is composed of the same elements as a proteid and in somewhat similar proportions, and may be regarded as an outlying member of this group. But gelatin is not a true proteid and cannot entirely replace it in food.

B. Non-nitrogenous Food-Stuffs.

(i) **Fats.**—These are composed of carbon, oxygen, and hydrogen only, and contain less oxygen than would form water if united to the hydrogen they contain. **Butter** and all animal and vegetable **oils** come under this head.

(ii) **Carbohydrates.**—These are substances which also consist of carbon, oxygen, and hydrogen only, but in them the oxygen is present in an amount which would just suffice to form water *if* it were united to their hydrogen. This group includes **starch**, as in flour or potatoes; ordinary **cane-sugar** or **beet-sugar**, and other sugars such as **dextrose** and **milk-sugar**; also **cellulose** from all vegetable tissues.

(iii) **Salts** and **Water.**—Water is present in all foods, and salts in most of them such as meat, eggs, milk, and cheese. The salts are chiefly the phosphates, chlorides, and carbonates of sodium, potassium and calcium, and some salts of iron.

All food is made up of these food-stuffs, but the amount of each present in different foods varies greatly. Thus lean meat is chiefly proteid, but ordinarily contains a good deal of fat; bread contains a great deal of carbohydrates, but also some proteid and a little fat. Only the fats and oils may be regarded as composed of nearly pure material. The composition of the chief foods is important and has been carefully determined; but to this we shall return when we come to study their respective influence on the body as a whole.

3. The purpose and means of Digestion.—All food-stuffs being thus proteids, fats, carbohydrates or mineral matters, pure or mixed up with other substances, the whole purpose of the alimentary apparatus is in the first place to separate these proteids, &c., from the innutritious residue, if there be any, and to reduce them into a condition either of solution or of excessively fine subdivision, in order that they may make their way through the delicate structures which form the walls of the vessels of the alimentary canal. In the next place this mechanical and physical change must be accompanied by chemical changes whereby the food-stuffs are brought into such a condition that when they reach the tissues the latter can take them up or *assimilate* them.

To these ends food is taken into the mouth and masticated, is mixed with saliva, is swallowed, undergoes gastric digestion, passes into the intestine, and is subjected to the action of the secretions of the liver and pancreas with which it there becomes mixed ; and, finally, after the more or less complete extraction of the nutritive constituents, the residue, mixed up with certain secretions of the intestines, leaves the body as the **fæces**.

The actual digestive changes of food are brought about chiefly by the action of fluids secreted by glands whose ducts pour their secretions into the cavity of the alimentary canal. These glands are essentially groups of cells supplied with nerves and blood-vessels ; but the arrangement of these cells may be simple or complicated, as in the types shown in Fig. 68.

Thus the glands of the walls of the intestines are tubular (1). Those in the walls of the stomach are also tubular but divided into two or more parts at their inner end (2). The salivary glands and the pancreas are more complicated ; their ducts divide and subdivide into multitudes of smaller tubes, each of which ends in a dilatation in which the secreting cells lie (6). These dilatations, attached to the branched ducts, somewhat resemble a

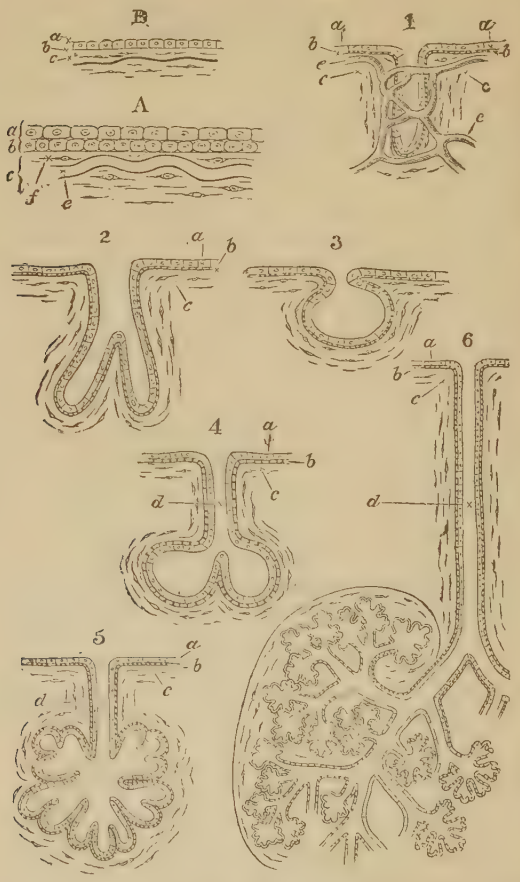


FIG. 68.—A DIAGRAM TO ILLUSTRATE THE STRUCTURE OF GLANDS.

A. Typical structure of the mucous membrane. *a*, an upper, and *b* a lower, layer of epithelium cells; *c*, the dermis with *e* a blood-vessel, and *f*, connective tissue corpuscles.

nch of grapes, whence glands of this type are called *emose*.

4. Mastication and Swallowing.—The cavity of the outh is a chamber with a fixed roof, formed by the **ard palate** (Fig. 69, *l*), and with a movable floor, nstituted by the lower jaw, and the tongue (*k*), which ls up the space between the two branches of the jaw. rching round the margins of the upper and the lower ws are the thirty-two teeth, sixteen above and sixteen low, and external to these, the closure of the cavity of he mouth is completed by the cheeks at the sides, and y the lips in front.

When the mouth is shut the back of the tongue comes to close contact with the palate; and, where the hard alate ends, the communication between the mouth and he back of the throat is still further impeded by a sort of eshy curtain—the **soft palate** or **velum**—the middle f which is produced into a prolongation, the **uvula** (*f*), hile its sides, skirting the sides of the passage, or **auces**, form double muscular pillars, which are termed he *pillars of the fauces*. Between these the **tonsils** are tuated, one on each side.

The velum with its uvula comes into contact below with he upper part of the back of the tongue, and with a sort f gristly, lid-like process connected with its base, the **piglottis** (*e*).

Behind the partition thus formed lies the cavity of the **pharynx**, which may be described as a funnel-shaped ag with muscular walls, the upper margins of the slanting, wide end of which are attached to the base of the skull,

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3. The same, with only one layer of cells, *a*, and *b*, the so-called basement membrane between the epithelium *a*, and dermis *c*.
1. A simple tubular gland.
2. A tubular gland bifid at its base. In this and succeeding figures the blood-vessels are omitted.
3. A simple saccular gland.
4. A divided saccular gland, with a duct, *d*.
5. A similar gland still more divided.
6. A racemose gland part only being drawn.

while the lateral margins are continuous with the sides, and the lower with the floor, of the mouth. The narrow

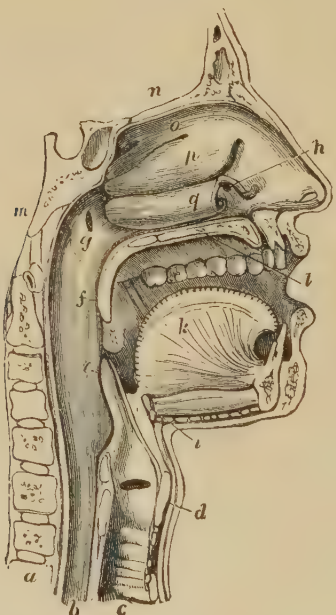


FIG. 69.—A SECTION OF THE MOUTH AND NOSE TAKEN VERTICALLY, A LITTLE TO THE LEFT OF THE MIDDLE LINE.

a, the vertebral column ; *b*, the œsophagus or gullet ; *c*, the wind-pipe ; *d*, the thyroid cartilage of the larynx ; *e*, the epiglottis ; *f*, the uvula ; *g*, the opening of the left Eustachian tube ; *h*, the opening of the left lachrymal duct ; *i*, the hyoid bone ; *k*, the tongue ; *l*, the hard palate ; *m*, *n*, the base of the skull ; *o*, *p*, *q*, the superior, middle, and inferior turbinal bones. The letters *g*, *f*, *e*, are placed in the pharynx.

end of the pharyngeal bag passes into the gullet or œsophagus (*b*), a muscular tube, which affords a passage into the stomach.

There are no fewer than six distinct openings into the nt part of the pharynx—four in pairs, and two single es in the middle line. The two pairs are, in front, the nder openings of the nasal cavities ; and at the sides, se to these, the apertures of the **Eustachian tubes** The two single apertures are, the hinder opening of mouth between the soft palate and the epiglottis ; and, hind the epiglottis, the upper aperture of the respirary passage, or the **glottis.**

Each of the thirty-two teeth which have been mentioned nsists of a **crown** which projects above the gum, and one or more **fangs**, which are embedded in sockets, or hat are called **alveoli**, in the jaws (see Fig. 3).

The eight teeth on opposite sides of the same jaw are nstructed upon exactly similar patterns, while the eight eth which are opposite to one another, and bite against ne another above and below, though similar in kind, ffer somewhat in the details of their patterns.

The two teeth in each eight which are nearest the iddle line in the front of the jaw, have wide but sharp nd chisel-like edges. Hence they are called **incisors**, r cutting teeth. The tooth which comes next is a ooth with a more conical and pointed crown. It answers o the great tearing and holding tooth of the dog, and is alled the **canine** or eye-tooth. The next two teeth have roader crowns, with two cusps, or points, on each crown, ne on the inside and one on the outside, whence they re termed **bicuspid** teeth, and sometimes false grinders. All these teeth have usually one fang each, except the bicuspid, the fangs of which may be more or less completely divided into two. The remaining teeth have two or three fangs each, and their crowns are much broader. As they crush and grind the matters which pass between them they are called **molars**, or true grinders. In the upper jaw their crowns present four points at the four corners, and a diagonal ridge connecting two of them. In the lower jaw the complete pattern is five-pointed,

there being two cusps on the inner side and three on the outer. Each tooth presents a **crown**, which is visible in the cavity of the mouth, where it becomes worn by attrition with the tooth opposite to it and with the food; and one or more **fangs**, which are buried in a socket furnished by the jawbone and the derma of the dense mucous membrane of the mouth, which constitutes the **gum**. The line of junction between the crown and the

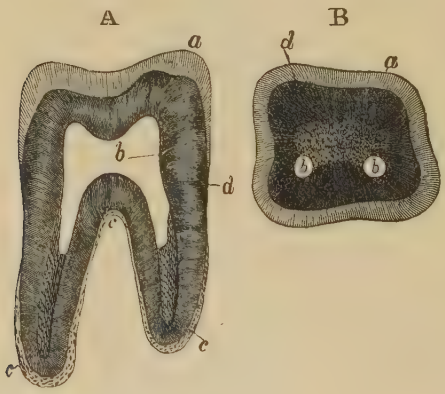


FIG. 70.

A, vertical, B, horizontal section of a tooth.—*a*, enamel of the crown; *b*, pulp cavity; *c*, cement of the fangs; *d*, dentine. (Magnified about three diameters.)

fang is the **neck** of the tooth. In the interior of the tooth is a cavity communicating with the exterior by canals, which traverse the fangs and open at their points. This cavity is the **pulp cavity**. It is occupied and completely filled by a highly vascular tissue richly supplied with nerves, the **dental pulp**, which is continuous below, through the openings of the fangs, with the vascular dermis of the gum which lies between the fangs

d the alveolar walls, and plays the part of periosteum both.

The tissue which forms the chief constituent of a tooth termed **dentine** (Fig. 70, A, B, *d*). It is a dense cified substance containing less animal matter than ne, and further differing from it in possessing no unæ, or proper canaliculi. Instead of these it presents numerable, minute, parallel, wavy tubules (Fig. 71, *d*), ich give off lateral branches. The wider inner ends of ese tubules may measure 4μ or 9μ ($\frac{1}{5000}$ inch); they en into the pulp cavity, while the narrower outer minations ramify at the surface of the dentine, and y even extend into the enamel or cement (Fig. 71).

The greater part of the crown and almost the whole of e fangs consist of dentine. But the summit of the own is invested by a thick layer of a much denser tissue, ich contains only 2 per cent. of animal matter, and is e hardest substance in the body; so hard that it will ike fire with steel. This is called **enamel** (Fig. 70, B, *a*). It becomes thinner on the sides of the crown d gradually dies out on the neck. Examined microopically, the enamel is seen to consist of six-sided ismatic fibres (Fig. 71, A, B) set closely side by side, arly at right angles to the surface of the dentine. ese fibres measure not more than 3μ to 5μ ($\frac{1}{5000}$ to $\frac{1}{2000}$ inch) in transverse diameter and present transverse iations.

The third tissue found in teeth is a thin layer of true ne, generally devoid of Haversian canals, which invests e outer surface of the fangs and thins out on the neck. is is termed **cement** (Fig. 70, A, *c*; and Fig. 71, C).

The dental pulp is chiefly composed of delicate conctive tissue. It is abundantly supplied with vessels and rves, which enter it through the small opening at the tremity of the fang. The nerves are mainly sensory anches derived from the fifth pair of cranial nerves.

The superficial part of the pulp, which is everywhere in

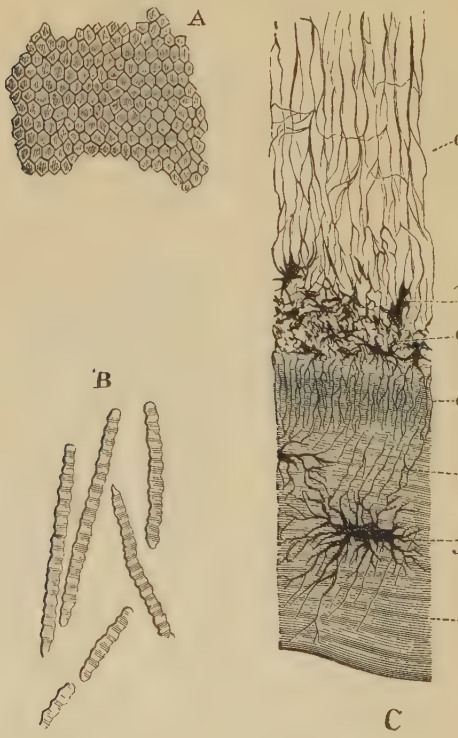


FIG. 71.

A. Enamel fibres viewed in transverse section.
B. Enamel fibres separated and viewed laterally.
C. A section of a tooth at the junction of the dentine (*a*) with the cement (*e*); *b*, *c*, irregular cavities in which the tubules of the dentine end; *d*, fine tubules continued from them; *f*, *g*, lacunæ and canaliculi of the cement. (Magnified about 400 diameters.)

immediate contact with the inner surface of the dentine, consists of a layer of nucleated cells so close set that they

rst resemble an epithelium. They are, however, in ty connective-tissue cells, and the layer is merely a tly modified condition of the stratum of undifferen- d connective tissue, which lies at the surface of y dermic structure, and from them long filamentous sses can be traced into the dentinal tubules.[1]

he muscles of the parts which have been described such a disposition that the lower jaw can be de- sed, so as to open the mouth and separate the teeth ; ised, in such a manner as to bring the teeth together ; nore obliquely from side to side, so as to cause the of the grinding teeth and the edges of the cutting h to slide over one another. And the muscles which form the elevating and sliding movements are of great ngth, and confer a corresponding force upon the ding and cutting actions of the teeth.

When solid food is taken into the mouth, it is cut and nd by the teeth, the fragments which ooze out upon outer side of their crowns being pushed beneath them n by the muscular contractions of the cheeks and ; while those which escape on the inner side are st back by the tongue, until the whole is thoroughly bed down.

While mastication is proceeding, the salivary glands r out their secretion in great abundance, and the va mixed with the food, which thus becomes inter- netrated not only with the salivary fluid, but with the which is entangled in the bubbles of the saliva.

When the food is sufficiently ground it is collected, veloped in saliva, into a mass or bolus, which rests on the back of the tongue, and is carried backwards to aperture which leads into the pharynx. Through this s thrust, the soft palate being lifted and its pillars being ught together, while the backward movement of the gue at once propels the mass and causes the epiglottis incline backwards and downwards over the glottis,

[1] The development of teeth is described in Lesson XII.

and so to form a bridge by which the bolus can trave over the opening of the air-passage without any risk o tumbling into it. While the epiglottis directs the cours of the mass of food below, and prevents it from passin into the trachea, the soft palate guides it above, keeps i out of the nasal chamber, and directs it downwards an backwards towards the lower part of the muscular pha ryngeal funnel. By this the bolus is immediately seize and tightly held, and the muscular fibres contracting above it, while they are comparatively lax below, it is rapidly thrust into the œsophagus.

The œsophagus is lined with mucous membrane. This rests on some fibrous tissue, outside of which is a thick coat of muscular tissue, striated in the upper third of the tube, unstriated lower down next to the stomach. This is arranged in two layers, an outer layer in which the fibres run parallel to the long axis of the tube ; an inner layer in which the fibres are wrapped round the tube.

When food has been thrust into the œsophagus by the action of the pharynx, the muscular wall of the œsophagus just above the bolus contracts and pushes it down into the next lower part. Then the wall of this part contracts and pushes the mass a little further down and so on. In this way the food is finally thrust into the stomach by a series of contractions of each part of the œsophagus in succession : this is spoken of as **peristaltic action.**

Drink is taken in exactly the same way as food. It does not fall down the pharynx and gullet, but each gulp is grasped and passed down. Hence it is that jugglers are able to drink standing upon their heads, and that a horse, or ox, drinks with its throat lower than its stomach, feats which would be impossible if fluid simply fell down the gullet into the gastric cavity.

During these processes of mastication, insalivation, and deglutition, what happens to the food is, first, that it is reduced to a coarser or finer pulp : secondly, that any

ers it carries in solution are still more diluted by
water of the saliva ; thirdly, that any starch it may
in begins to be changed into sugar by the saliva,
e formation and action we must next consider.

The Salivary Glands.—The mucous membrane
lines the mouth and the pharynx is beset with
ite glands, the *buccal glands* ; but the great glands
which the cavity of the mouth receives its chief

FIG. 72.

lissection of the right side of the face, showing, *a*, the sublingual,
e submaxillary glands, with their ducts opening beside the tongue
e floor of the mouth at *d* ; *c*, the parotid gland and its duct, which
s on the side of the cheek at *e*.

etion are the three pairs which, as has been already
tioned, are called **parotid, submaxillary, sub-
gual**, and which secrete the principal part of the
va (Fig. 72).

ach parotid gland is placed just in front of the ear,
its duct passes forwards along the cheek, until it
as in the interior of the mouth, opposite the second
er grinding tooth.

The submaxillary and sublingual glands lie between the lower jaw and the floor of the mouth, the submaxillary being situated further back than the sublingual. Their ducts open in the floor of the mouth below the tip of the tongue. The secretion of these salivary glands, mixed with that of the small glands of the mouth, constitutes the **saliva**.

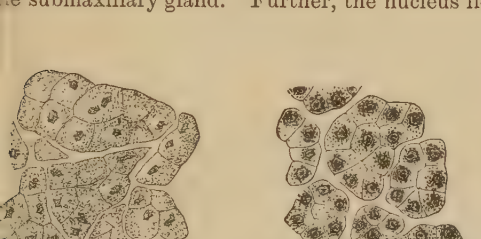
The salivary glands are built up on the type shown in Fig. 68, 6. The essential part of the structure lies in the

FIG. 73.—SECTIONS OF THE SUBMAXILLARY GLAND.
A, at rest; B, after secretory activity.
a, *a*, demilune cells.

cells which line the dilated ends, or **alveoli**, of the finest branches of their ducts. In a section of a submaxillary gland which is *resting*, that is, *has not been secreting for some time*, the cells are large and nearly fill the alveoli. Each cell has a nucleus placed near its outer end and surrounded by a small amount of protoplasm which is granular and stains readily. The (larger) rest of the cell is quite clear and transparent and stains with great difficulty if at all (Fig. 73, A). Since the material compos

his clear part of the cell is of the nature of mucin, ubmaxillary gland is spoken of as a **mucous gland.** some of the alveoli a second kind of cell may be (Fig. 73, A and B, *a*); these lie close against the wall of the alveolus, and from their shape are often demilune cells. They are granular and stain y.

similar sections of the parotid gland, also *in the g condition*, the cells are smaller than in the alveoli e submaxillary gland. Further, the nucleus lies near



A *B*

FIG. 74.—SECTIONS OF THE PAROTID GLAND.
A, at rest; B, after secretory activity.

middle of each cell, and the whole cell is extremely ular and stains fairly easily (Fig. 74, A). The body ach cell is composed of albumin and is free from any e of anything like mucin; hence the parotid is known **albuminous gland.**

fter these glands have been *secreting for some time*, e result either of taking food or of stimulating the es supplied to them, the appearance of their cells is ly changed. The cells of the submaxillary gland are *smaller*; the nucleus is nearer the centre of each cell

and the whole cell stains readily (Fig. 73, B). In the parotid gland the cells are *similarly smaller*, the nucleus more distinct, and the cell-substance stains more readily than in the condition of rest (Fig. 74, B).

If instead of taking sections of the hardened gland a piece of the *fresh* parotid be examined in the two states of rest and activity the differences shown in Fig. 75 may be seen.

At rest the cells are *full of granules* throughout, as in Fig. 75, *A*. After activity the granules are *fewer* and now lie *near the inner end* of the cells as in *C*. Between

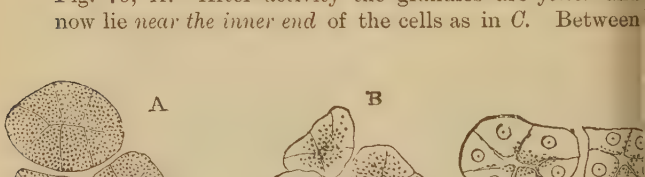


FIG. 75.—CHANGES IN THE PAROTID GLAND DURING SECRETING ACTIVITY. (SLIGHTLY DIAGRAMMATIC.)

these two extremes there is an intermediate stage shown in *B*.

6. The Nervous Control and Nature of Salivary Secretion.—We have described in the preceding section the differences which may be observed between the cells of a resting gland and of the same gland after it has been secreting. Let us now see what may be learnt from a study of these differences and of the way in which they may be brought about.

In the first place the differences in the size and appearance of the cells in the two conditions seem to show quite clearly that while at rest they build up material which is stored in their substance and hence the cells are large

the submaxillary gland this substance is chiefly
ous, in the parotid albuminous, and some of it is
ited as separate distinct granules in the body of the
Fig. 75, A). Further it appears that during their
y both glands discharge their store of material into
uct leading from them and hence become smaller.

further, the submaxillary gland is supplied by a
which is a branch of the VIIth cranial nerve (see
n XI.) and which, since it crosses the tympanic
or drum of the ear (see Lesson VIII.) is called the
rda tympani nerve. When this nerve is stimulated
things happen ; the arteries which supply the gland
blood dilate and there is a very largely increased flow
od through the gland ; the gland begins to pour out
cretion ; and the cells of the gland slowly change their
nd appearance as already described. These changes
that a good deal of the material with which they
loaded during rest has been discharged. But at the
time the cells have discharged a large quantity of
, for saliva, like all other secretions, except the
tion of the sebaceous glands (p. 197), is largely com-
d of water, and this water can only have come from
lood. We are thus at once face to face with the
ion ;—has the increased supply of blood simply led
increased flow of water through the cells which has
ed away with it the accumulated materials of the cell-
ance, the whole process being largely filtrational, or
*e stimulation of the nerve made the cells not only dis-
e some of their substance, but also made them take up
from the blood and pass this as well through them-*
? The answer to this question is simple and the
nce in its support is conclusive.

increased temporary secretion may be observed on
lating the nerve even after the blood-supply to the
has been cut off, and if some drug, such as atropine,
jected into the animal, then although the arteries
to the full extent when the nerve is stimulated, no

increased secretion takes place. No clearer proof could be desired to show that when the gland secretes it is because *the impulses which reach it along the nerve exert a direct influence on its cells.* These impulses make the cells take up water and discharge it, together with some of their stored up cell-substance, as saliva which passes as the secretion of the gland into the ducts. It is thus not the increased blood-supply which causes the secretion, although of course it is necessary if the cells are to continue to secrete, for it is from the blood alone that they can obtain all that they require for the manufacture of their secretion.

Saliva is ordinarily secreted in increased quantity as soon as food is introduced into the mouth. This result is brought about reflexly. The food stimulates the ends of certain nerves (Vth and IXth cranial, see Lesson XI.), which supply the walls of the inside of the mouth. Impulses pass up these nerves to the brain, and from this other impulses pass out down to the submaxillary gland and make its cells secrete.

7. The Composition and Action of Saliva.—The mixed saliva from the several glands consists chiefly of water, holding in solution a small amount of proteid matter, some inorganic salts to which its faintly alkaline reaction is due, a small amount of mucin, which gives to saliva its well-known sliminess, and a small quantity of a peculiar substance called **ptyalin,** which has certain very remarkable properties. It does not act on proteids or fats, but if a little saliva, *i.e.* ptyalin, be mixed with ordinary starch-paste and warmed to the temperature of the body, it turns that starch into a sugar identical with that obtained from malt in brewing and hence known as **maltose.**

But although this chemical change is without doubt of some use to the body, its importance must not be overestimated. For in many animals the action of their saliva on starch is very slight, and moreover (see p. 262) the larger

t of the starch we eat is digested, that is changed
o a sugar, while the food is in the intestine and
ler the action of the pancreatic juice. The chief use
the saliva is mechanical rather than chemical, inasmuch
it moistens the food and thereby assists mastication
i makes deglutition, or the swallowing of food, easy.

8. Soluble Ferments or Enzymes.—The peculiar
stance, ptyalin, to which the chemical action of saliva
starch is due, belongs to a class of substances known
soluble ferments or enzymes. The word ferment was
ginally applied to a living organism such as yeast which,
in the case of brewing, while converting the sugar in
wort into alcohol causes at the same time, on account
the simultaneous production of carbonic acid gas, a
ling up or frothing of the liquor; hence the name
rment (*fervere* = to boil up).

But it is known now that such organised ferments can
made to yield extracts which may be filtered so as to
quite free from organisms and still be able to produce
e same changes as did the cells from which they are
epared. Hence the name of soluble ferment or enzyme
$\mu\eta$ = yeast) was given to the substance in solution which
a bring about the same changes as the parent cell.

Very little is known of the chemical nature of enzymes,
t they are strongly characterised by certain facts as to
e conditions under which their action takes place.
hus: (i) Very minute quantities will effect a change in
mass of the substance on which they are working which
enormously large compared with the minute mass of
e enzyme. (ii) Their action depends closely on tempera-
re. At 0° C. (32° F.) they cease to act; as the tempera-
re rises they become increasingly active, and are most
tive at about 40° C. (104° F.). At higher temperatures
ey become less active and lose their powers permanently
once heated to 100° C. (212° F.) as by boiling: they are
en said to be "killed." (iii) Their action in many cases
epends on the reaction, whether acid or alkaline or

neutral, of the solution in which they are at work.[1] (iv) Their action stops in presence of an excess of the special products of their activity, and (v) It has not so far been conclusively proved that the enzymes are themselves used up during the changes which they produce on other substances.

Nearly all the chemical changes which the food undergoes in the alimentary canal are brought about by the action of these soluble ferments or enzymes.

9. The Structure of the Stomach.—The stomach, like the gullet, consists of a tube with muscular walls composed of smooth muscular fibres, and lined by mucous membrane; but it differs from the gullet in several circumstances. In the first place, its cavity is greatly larger, and its left end is produced into an enlargement which, because it is on the heart side of the body, is called the **cardiac dilatation** (Fig. 76, *b*). The opening of the gullet into the stomach, termed the **cardiac aperture**, is consequently nearly in the middle of the whole length of the organ, which presents a long, convex, **greater curvature**, along its front or under edge, and a short, concave, **lesser curvature**, on its back or upper contour. Towards its right extremity the stomach narrows, and, where it passes into the intestine, the muscular fibres are so disposed as to form a sort of sphincter around the aperture of communication. This is called the **pylorus** (Fig. 76, *d*).

The muscular coat of the stomach, consisting of unstriated muscular tissue, is made up of two layers, an outer longitudinal and an inner circular, together with a certain amount of muscle fibres which are continuous with the circular fibres of the œsophagus and which, running **obliquely**, merge into the internal circular layer of the stomach. The mucous membrane which

[1] Thus the pepsin of gastric juice acts best in presence of hydrochloric acid and the trypsin of pancreatic juice in presence of sodium carbonate.

es the stomach is loosely attached to the muscular coat a layer of fibrous connective tissue. This is called the mucous coat, and it is in this layer that the nerves, od-vessels and lymphatics run for the supply of the cous membrane.

The mucous membrane lining the wall of the stomach tains, or rather is made up of, a multitude of small

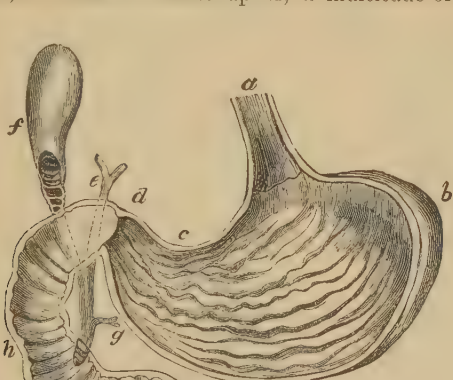


FIG. 76.—THE STOMACH LAID OPEN.

, the œsophagus ; *b*, the cardiac dilatation ; *c*, the lesser curvature ; the pylorus ; *e*, the biliary duct ; *f*, the gall-bladder ; *g*, the pancreatic ct, opening in common with the cystic duct opposite *h* ; *h*, *i*, the odenum.

nds, packed closely side by side, which open upon its rface. These are on the whole simple in nature, being ng tubular glands, but they vary in character, their nd ends being more divided and twisted at one part the stomach than another.

Each gland is lined by cells which at the mouth of the nd are columnar and secrete mucin ; but deeper down in

the tubes they are cubical and slightly granular. These are the **central cells** (Fig. 77, *c*). A second kind of cell may also be seen lying irregularly scattered between the outer wall of the gland and its central cells: these are the **parietal or ovoid cells** (Fig. 77, *p*). Oval in shape, they have a well-defined outline and their cell-substance is usually very distinctly granular. The glands near the pyloric end of the stomach differ from those of the rest of the mucous membrane, chiefly and essentially by not containing any of these ovoid cells.

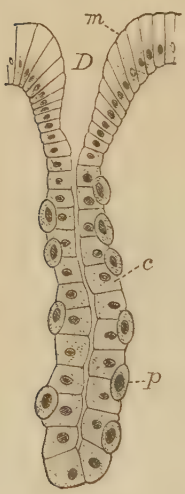


FIG. 77.—ONE OF THE GLANDS WHICH SECRETES GASTRIC JUICE.

D, the duct or mouth of the gland; *m*, mucous cells lining the mouth of the gland and covering the inner surface of the mucous membrane; *c*, central cells; *p*, parietal or ovoid cells.

When the stomach is empty, its mucous membrane is pale and hardly more than moist. Its small arteries are then in a state of constriction, and comparatively little blood is sent through it. On the entrance of food a vaso-motor action is set up, which causes these small arteries to dilate; the mucous membrane consequently receives a much larger quantity of blood, and it becomes very red. At the same time the cells of the gland begin to form their secretion, taking the material they require for this purpose out of the extra supply of blood now coming to them. The whole process is *exactly similar in principle* to that already described in the case of the secretory activity of the submaxillary gland (p. 240).

The secretion thus formed is the **gastric juice.**

10. The Nature and Action of Gastric Juice.—Pure

astric juice is a clear, acid fluid and consists of little ore than water, containing a few saline matters in solu- n, and its acidity is due to the presence of free **ydrochloric acid** to the extent of ·2 per cent. It ossesses, however, in addition a small quantity of a uliar substance called **pepsin**, a soluble ferment enzyme in many respects similar to, though very fferent in its effects from ptyalin, and also a similar rment called **rennin.**

It is easy to ascertain the properties of gastric juice perimentally, by putting a small portion of the mucous embrane of a stomach into water made acid by the ldition of ·2—·5 per cent. of hydrochloric acid and con- ining small pieces of meat, hard-boiled egg, or other roteids, and keeping the mixture at a temperature of bout 40° C. (104° F.). After a few hours it will be und that the white of egg, if not in too great quantity, as become dissolved : while all that remains of the meat a pulp, consisting chiefly of the connective tissue and tty matters which it contained. This is *artificial diges- on*, and it has been proved by experiment that precisely ne same operation takes place when food undergoes atural digestion within the stomach of a living animal.

It takes a very long time (some days) for the dilute acid one to dissolve proteid matters, and hence the solvent ower of gastric juice must be chiefly attributed to the epsin ; moreover gastric juice which has been boiled, in hich case all the ferment it contains is "killed" (see 241), is quite inactive although it contains the usual nount of acid.

Thus gastric juice dissolves proteids, and the character- tic proteid which is formed during the solvent action of e juice is called **peptone**, and has pretty much the me characters whatever the nature of the proteid which as been digested.

The **rennin** of gastric juice is a ferment which causes e casein in milk to clot in a way very similar to that in

which fibrin-ferment gives rise to a clot of fibrin by its action on fibrinogen (p. 115). This is the basis of cheese-making, and the "rennet" used for obtaining the curd in this process is really an extract of the mucous membrane of the stomach of a calf, in which the ferment is peculiarly plentiful.

Peptone differs from all other proteids in its extreme solubility, and characteristically in the fact that it is *highly diffusible*, and hence in the readiness with which it passes through animal membranes. Many proteids, as fibrin, are naturally insoluble in water, and others, such as white of egg, though apparently soluble, are not completely so, and can be rendered quite solid or coagulated by being simply heated, as when an egg is boiled. A solution of peptone however is perfectly fluid, does not become solid, and is not at all coagulated by boiling. Again, if a quantity of albumin, such as white of egg or serum of blood, be tied up in a bladder, and the bladder immersed in water, very little if any of the proteid will pass through the bladder into the water, provided that there are no holes.[1] If, however, peptone be used instead of albumin, a very large quantity will speedily pass through into the water, and a quantity of water will pass from the outside into the bladder, causing it to swell up. This diffusive passage of a substance through a membrane is called **osmosis**, and is evidently of great importance in the economy; and the purpose of the conversion of the various proteids by digestion into peptone seems to be, in part at least, to enable this class of food-stuff to pass readily into the blood through the thin partition formed by the walls of the mucous membrane of the intestine and the coats of the capillaries. Similarly, starch, even when boiled, and so partially dissolved, is not diffusible and will not pass through membranes, whereas sugar does so with the greatest ease. Hence

[1] This experiment may be readily made with the apparatus shown in Fig. 38, p. 121.

reason of the conversion of starch, by digestion, into gar.

As far as we know gastric juice has no direct action on s; by breaking up, however, the proteid framework in ich animal and vegetable fats are imbedded, it sets se free, and so helps their digestion by exposing them he action of other agents. It appears too, that gastric ee has no direct action on carbohydrates; on the ntrary, the conversion of the starch into sugar begun in e mouth appears to be wholly or partially arrested by e acidity of the contents of the stomach, ptyalin being tive only in an alkaline or neutral mixture.

By continual rolling about, with constant additions of stric juice, the food becomes reduced to the consistence pea-soup, and is called **chyme**. In this state, the rger part is allowed to escape through the pylorus and to ter the duodenum; but a portion of the fluid (consisting peptone together with any sugar resulting from the rtial conversion of starch, or otherwise) may be at once sorbed, making its way, by imbibition, through the alls of the delicate and numerous vessels of the stomach to the current of the blood, which is rushing through e gastric veins to the portal vein.

11. The General Arrangement and Structure of the ntestines.—The intestines form one long tube, with ucous and muscular coats, like the stomach; and, like they are enveloped in peritoneum. They are divided to two portions—the **small intestines** and the **large ntestines**; the latter, though shorter, having a much reater diameter than the former. The name of **duo-enum** is given to that part of the small intestine, bout ten inches in length, which immediately succeeds e stomach, and is bent upon itself and fastened by e peritoneum against the back wall of the abdomen, in e loop shown in Fig. 76, *h*, *i*. It is in this loop that e head of the pancreas lies (Fig. 67).

The rest of the small intestines, of which the part next

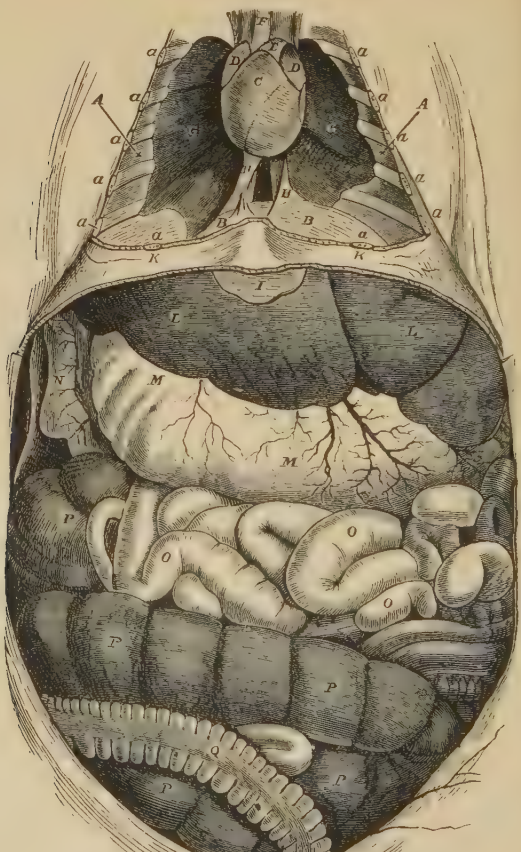


FIG. 78.—THE VISCERA OF A RABBIT AS SEEN UPON SIMPLY OPENING THE CAVITIES OF THE THORAX AND ABDOMEN WITHOUT ANY FURTHER DISSECTION.

A, cavity of the thorax, pleural cavity on either side; *B*, diaphragm; *C*, ventricles of the heart; *D*, auricles; *E*, pulmonary artery; *F* aorta;

e duodenum is called the **jejunum** and the rest the
m, is no wider than the duodenum, so that the tran-
from the small intestine to the large (Fig. 79, *a*) is
sudden. The opening of the small intestine into
arge is provided with prominent lips which project
he cavity of the latter, and oppose the passage of
ers from it into the small intestine, while they readily
of a passage the other way. This is the **ileo-cæcal**
ve (Fig. 79, *d*).
e large intestine forms a blind dilatation beyond the

FIG. 79.

termination of the ileum, *a*, in the cæcum, and the continuation
latter into the colon, *c*; *d*, the ileo-cæcal valve; *e*, the aperture of
ermiform appendix (*b*) into the cæcum.

cæcal valve, which is called the **cæcum**; and from
an elongated, blind process is given off, which, from

gs collapsed, and occupying only back part of chest; *H*, lateral
ns of pleural membranes; *I*, cartilage at the end of sternum
orm cartilage); *K*, portion of the wall of body left between thorax
bdomen: *a*, cut ends of the ribs; *E*, the liver, in this case lying
to the left than the right of the body; *M*, the stomach, a large part
greater curvature being shown; *N*, duodenum; *O*, small intestine;
e cæcum, so largely developed in this and other herbivorous
ls; *Q*, the large intestine.

its shape, is called the **vermiform appendix** of the cæcum (Fig. 79, *b*).

The cæcum lies in the lower part of the right side of the

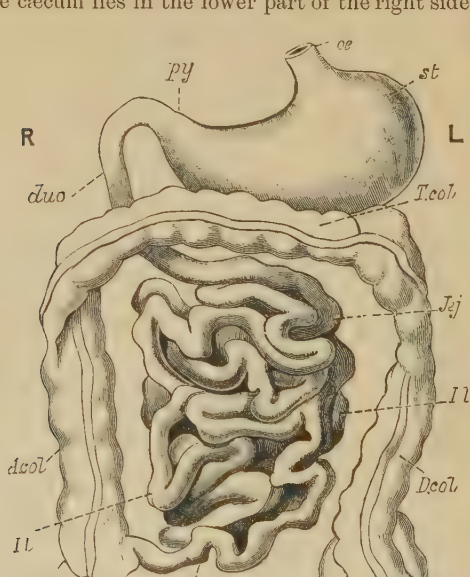
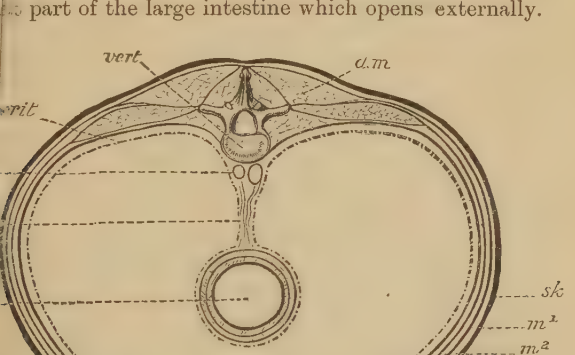


FIG. 80.—THE ALIMENTARY CANAL IN THE ABDOMEN.

R, right; L, left; *œ*, œsophagus; *st.* stomach; *py.* pylorus; *duo.* duodenum; *Jej.* jejunum; *Il.* ileum; *cæc.* cæcum; *A.col.* ascending colon; *T.col.* transverse colon; *D.col.* descending colon; *R*, rectum; *verm.* vermiform appendix.

abdominal cavity. The **colon**, or first part of the large intestine, passes upwards from it as the **ascending colon**; then making a sudden turn at a right angle, it

s across to the left side of the body, being called the **sverse colon** in this part of its course; and next nly bending backwards along the left side of the nen, it becomes the **descending colon.** This s the middle line and becomes the **rectum,** which part of the large intestine which opens externally.



1.—Diagram to show how the Wall of the Abdomen is made up, and how the Mesentery supports the Intestine.

body is supposed to be cut across, and the intestine is represented section of a straight tube. In reality the space between the ine and the body wall is filled by the coils of the intestine and by organs.

. vertebra; *d.m*, muscles of back; *sk*. skin; m^1, m^2, m^3, the three e layers; *perit*. peritoneum; *mes*. mesentery; *intest*. intestine; *b.v*, vessels.

e intestines are slung from the middle line, along ertebral column, of the abdominal cavity by a thin brane known as the **mesentery.** This consists y of two layers between which the nerves, blood-ls and lymphatics lie which supply the intestines. e layers are continued outwards on each side from

the middle line as a lining, the **peritoneum**, for the whole cavity of the abdomen, and also pass over and round the intestines. The latter thus lie in a fold of the peritoneum, somewhat as a man lies when slung in a hammock (Fig. 81).

Other folds of the peritoneum similarly support the other organs in the abdomen. The peritoneum is thus a double bag whose relation to the wall of the abdomen and to the organs in it is similar to that of the pleuræ to the walls of the thorax and the lungs.

The intestines receive their blood almost directly from the aorta. Their veins carry the blood which has traversed the intestinal capillaries to the portal vein.

The intestines are made up of four coats: an external thin *serous* covering of connective tissue, beneath which is a *muscular* coat connected by a *submucous* layer with the inner or *mucous* coat.

The muscular coat of the small intestines is made up of two layers; an outer longitudinal, an inner circular. The circular fibres of any part are able to contract, successively in such a manner that the upper fibres, or those nearer the stomach, contract before the lower ones, or those nearer the large intestine. It follows from this so-called *peristaltic contraction*, that the contents of the intestine are constantly being propelled, by successive and progressive narrowing of their calibre, from their upper towards their lower parts. And the same peristaltic movement goes on in the large intestine from the ileo-cæcal valve to the anus.

The submucous layer is composed of loose (areolar) connective tissue, and carries the blood-vessels, nerves and lymphatics.

The tube of mucous membrane which forms the inner coat of the small intestines is larger than the muscular tube which surrounds it; hence to get this greater length in the former stowed away into the shorter length of

ular tubing the mucous membrane is thrown into which must evidently lie at right angles to its long These folds serve to increase the surface of the us membrane and are called **valvulæ conni-tes.**

e large intestine presents noteworthy peculiarities arrangement of the longitudinal muscular fibres of olon into three bands, which are shorter than the of the intestine itself, so that the latter is thrown puckers and pouches (Fig. 78, Q); these are known e **sacculi,** and serve for the same purpose as the *lvæ conniventes* of the small intestine. Moreover, the ular fibres around the termination of the rectum are nged so as to form a ring-like sphincter muscle, which s the aperture firmly closed, except when defæca-takes place.

ie mucous membrane of both small and large intestine ists mainly of a number of simple tubular glands ed side by side; they are known as the **glands of berkühn** (Fig. 82, G.L). In the small intestine tissue between the mouths of the neighbouring ds is at frequent intervals thrown out into the y of the intestine as club-shaped processes or ections, the **villi,** which are thus set side by over the surface of the mucous membrane like the on velvet. These villi are absent in the large intes-

The glands of Lieberkühn are separated from each r by tissue which is practically the same as that dy described as lymphoid or adenoid tissue (p. 90); therefore a network of connective tissue fibres. erever a villus occurs this adenoid tissue is prolonged nto and forms the body of the villus, and in it run the branches of the blood-vessels and lymphatics supplied ch villus. Each gland of Lieberkühn is lined by a of cubical cells, among which occur a certain number nucous cells, and this layer is continued outwards each villus as its external covering; but the cells

covering the villi differ in shape from those lining th glands (Fig. 82, B, C).

At irregular intervals along the mucous membrane th lymphoid tissue between the glands is developed int small rounded masses called "**solitary glands**" o "**solitary follicles.**" These closely resemble th glandular substance of the alveoli at the cortex of a lym phatic gland (p. 90), and are similarly crowded with leuco cytes. In parts of the small intestine, more particularl in the ileum, groups of these follicles are found packe closely together; they are then known as "agminate glands," or **Peyer's patches**; these do not occur i the large intestine.

At the commencement of the duodenum are certai small racemose glands, called the glands of Brunner whose ducts open into the intestine. Their functio seems to be quite unimportant.

12. **The Structure of the Villi.**—A villus, as alread explained, is a projection into the cavity of the intestin of the tissue between the glands of Lieberkühn, and i covered by an epithelium continuous with that whic lines these glands. The average length of a villus is abou ·5—·7 of a millimetre ($\frac{1}{50}$—$\frac{1}{36}$ of an inch). Running up th centre or axis of the villus is a relatively large lymphati vessel which ends blindly at the summit of the villus, bu at its base opens into the lymphatics in the submucou tissue (Fig. 82, *l*). This central lymphatic is called **lacteal.** Lying around the lacteal and parallel to it, a a few small fibres of unstriated muscle derived from th **muscularis mucosæ,** which is a thin layer of u striated muscle in the mucous membrane, lying next t the submucous coat (Fig. 82, *m.m*); outside thes again, close under the epithelium of the villus, is a ne work of capillaries (Fig. 82, *c*), which receive blood fro an artery in the submucous layer and return it by a sma vein to the veins of the same layer.

All the space left in between the several structures

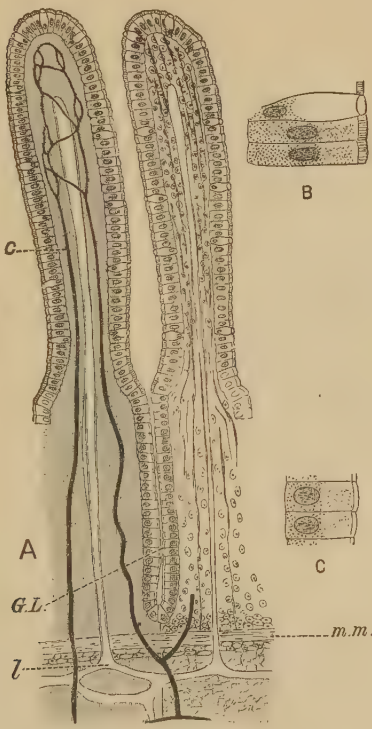


FIG. 82.—DIAGRAM OF TWO VILLI AND AN ADJACENT GLAND OF LIEBERKÜHN (HARDY).

A, two villi with a gland of Lieberkühn, G.L, between their bases; *m*, muscularis mucosæ; *l*, central lacteal; *c*, blood-capillaries. B, portion of epithelium of villus more highly magnified to show one "goblet" cell (above) and two of the other epithelial cells; C, two of the cells which line the tube of the gland of Lieberkühn, more highly magnified.

far described in the body of the villus is filled up wit adenoid (lymphoid) tissue, whose meshes are more or le crowded with leucocytes.

The epithelium covering a villus is made up of cells two kinds. Of these the large majority are tall, columna and granular, with an oval nucleus towards their inn end. The outer end of each cell (on the surface of t villus) shows a narrow, strongly striated border (Fig. 82 Lying between these are cells which, from their shap are often called "goblet" cells, but which in structure a practically the same as the mucous cells of the submaxilla gland already described (p. 236). These cells secrete t mucus which covers the ins de of the intestine. T columnar cells are concerned in the absorption of digest food.

13. The Structure of the Pancreas and its Chang during Secretion.—The pancreas is a racemose glan but the alveoli in which the ducts end are somewh elongated as compared with their more rounded shape in t salivary glands. The cells in each alveolus are not unli those of the parotid gland (p. 237). When the gland h been at rest for some time the cells are large, their outlin indistinct, and the central parts of each is thickly load with very obvious granules (Fig. 83, A). After the gla has been secreting for some time, the cells are small their outline distinct, and the granules have largely d appeared. Those granules which remain are now plac at the inner ends of the cells next to the lumen of t alveolus (Fig. 83, B). These differences in the appearan of the cells in the two conditions of rest and activ show quite clearly that while at rest these cells bu up material which is lodged in their substance as vious granules and discharge this material as part of t secretion as soon as they become active. Thus the chan taking place in the cells of the pancreas during cretion are essentially the same as those previou described in the case of the salivary glands, and ha

same significance in explanation of the phenomena cretion.

The Nature and Action of Pancreatic Juice.—reatic juice is a somewhat viscid fluid, alkaline from resence of sodium carbonate and containing a fairly amount of proteid in solution. It contains further, most important constituents, three soluble ferments. ese the chief is one which is called **trypsin**, and is so ike pepsin that it converts proteids into peptones,[1]

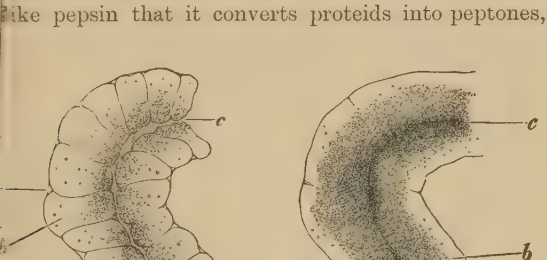


FIG. 83.—A PORTION OF THE PANCREAS OF A RABBIT.

at rest; B, in a state of activity.
granular central zone of the cells; *b*, clear outer zone; *c*, lumen of olus; *d*, junction of two neighbouring cells.

it differs from pepsin in several respects. In the t place trypsin is most active in an alkaline solution, h as of 1 per cent. sodium carbonate, while pepsin will y act in presence of an acid. In the next place, the nge which proteids undergo by the action of trypsin s not end with the formation of peptones, as it does he case of pepsin, but proceeds further, and some

[1] An artificial pancreatic digestion of proteids may be carried on in way already described for pepsin (p. 245), using as a digestive fluid a r cent. solution of sodium carbonate to which some of the extract of reas sold as "Liquor pancreaticus" has been added.

of the peptone is broken down into the crystalline substances known as leucine and tyrosine. Of these the leucine is peculiarly interesting, inasmuch as after it is absorbed it is carried to the liver in the blood of the portal vein and is by the liver converted into urea (see p. 189).

The second ferment in pancreatic juice is one which resembles the ptyalin of saliva in so far as it converts starch into sugar, but it acts more energetically, and the sugar it produces, though chiefly maltose (C_{12} H_{22} O_{11}), is mixed with a certain quantity of dextrose (C_6 H_{12} O_6).

The third ferment has no action on either proteids or carbohydrates, but it acts on the ordinary fats in such a way as to split them up into glycerine and a fatty acid. The latter uniting with the alkali of the pancreatic juice forms soaps, and this process is known as **saponification**. The soaps so formed are important, for they help greatly in reducing the fats to that state of fine subdivision, known as an **emulsion**,[1] which, as we shall see presently, is an important preliminary to the absorption of fat from the intestines.

Pancreatic juice, as containing these three ferments, acts therefore on all three classes of food-stuffs, peptonising the proteids, saponifying and emulsifying the fats, and converting starch into sugars.

Although the most obvious function of the pancreas is to secrete a digestive juice, there are reasons for supposing that it has other important uses. If it be removed from an animal, a large quantity of sugar (dextrose) speedily appears in the urine and the animal wastes away. Such a condition is not infrequently observed in man, and is known as **diabetes**; and in some cases of diabetes the pancreas has been found to be diseased

[1] When a substance is sub-divided into extremely minute particles suspended in a fluid under conditions such that these particles do not run together on standing, the substance is said to be emulsified and the fluid is called an emulsion. Thus milk is a typical emulsion.

is respect the pancreas seems to exert some control
the nutrition of the body in a way somewhat
r (though differing in its results) to the influence
d by the thyroid gland and the suprarenal bodies
. 220).

The Nature and Action of Bile.—Bile is the secreted by the liver (see p. 213). In the con- in which it may most ordinarily be observed it a greenish colour, but as it flows fresh from the it is bright yellow with a brownish tinge. This is due to a pigment called **bilirubin**. By rion this may be easily converted into a green nt called **biliverdin**, and the differences in the r of the bile of different animals depends on the ve amounts of these two pigments which they contain. e colouring matters are usually known as the **bile-ments**, and of these the bilirubin is probably, as ly stated (p. 105), formed from the hæmoglobin of d blood-corpuscles by some peculiar action of the of the liver. In addition to the pigments bile, which sts of about 85 per cent. of water, holds in solution n salts of sodium, the **bile-salts**. These are salts o organic acids, one called **glycocholic**, the other ocholic. The former consists of carbon, oxygen, ogen, and nitrogen, while the latter contains ad- nally a considerable quantity of sulphur.

e as it is secreted by the liver is a thin fluid, but after journ in the gall-bladder, where it is stored in the vals between its discharge into the intestines, it ins a considerable amount of **mucin**, secreted into the cells which line the gall-bladder and is now d and slimy.

e has of itself no direct chemical action on food-stuffs. s an alkaline fluid, poured into the intestine in large tity, it serves to neutralise the acidity of the chyme as ves the stomach and thus prepares it for the action ncreatic juice. Further it plays an important part,

when mixed with pancreatic juice, in leading to the emulsification of fats, and also facilitates their subsequent absorption. It also possesses well-marked antiseptic properties and thus prevents any undue putrefactive changes in the contents of the intestine.

16. The Changes Food Undergoes in the Intestines.—The only secretions, besides those of the proper intestinal glands, which enter the intestine, are those of the liver and the pancreas—the *bile* and the *pancreatic juice*. The ducts of these organs have a common opening in the middle of the bend of the duodenum; and, since the common duct passes obliquely through the coats of the intestine, its walls serve as a kind of valve, obstructing the flow of the contents of the duodenum into the duct but readily permitting the passage of bile and pancreatic juice into the duodenum (Figs. 67 and 76).

The glands of Lieberkühn are supposed to form a certain amount of a secretion known as **succus entericus** or intestinal juice, which they then discharge into the intestine. The precise functions of this secretion are but little known: in some animals it may possibly be able to convert starch slowly into sugar and to peptonise proteid. But on the whole it probably possesses very little importance as a digestive agent.

After gastric digestion has been going on some time and the semi-digested food begins to pass on into the duodenum, the pancreas comes into activity, its blood-vessels dilate, it becomes red and full of blood, its cells secrete rapidly, and a copious flow of pancreatic juice takes place along its duct into the intestine.

The secretion of bile by the liver is much more continuous than that of the pancreas, and is not so markedly increased by the presence of food in the stomach. There is, however, a store of bile laid up in the gall-bladder; and as the acid chyme passes into the duodenum and flows over the common aperture of the bile and pancreatic ducts, a quantity of bile from this reservoir in the

bladder is ejected into the intestine. The bile and creatic juice together here mix with the chyme and nce remarkable changes in it.

the first place, the alkali of these juices neutralises id of the chyme; in the second place, both the bile the pancreatic juice appear to exercise an influence the fatty matters contained in the chyme, which ates the subdivision of these fats into very minute te particles, and this action is specially well-marked bile and pancreatic juice are mixed. The fat, as it s from the stomach, is very imperfectly mixed with ther constituents of the chyme; and the drops of fat (for all the fat of the food is melted by the heat of tomach) readily run together into larger masses. By ombined action, however, of the bile and pancreatic the large drops of fat which pass into the intestine the stomach are *emulsified*, that is to say are broken nto exceedingly minute particles, and thoroughly d with the rest of the contents; they are brought in o very much the same condition as that in which .e. butter) exists in milk. When this emulsifying aken place the contents of the small intestine no r appear grey like the chyme in the stomach but and milky; in fact it and milk are white for the reason, viz., on account of the multitude of minute ended fatty particles reflecting a great amount of

e contents of the small intestine, thus white and y, are sometimes called *chyle*; but it is best to reserve name for the contents of the lacteals, of which we have to speak directly.

e emulsifying of the fats is not, however, the only ge going on in the small intestine. The pancreatic has an action on starch similar to that of saliva, but more powerful. During the short stay in the h very little starch has had time to be converted into , and in the stomach, as we have seen, the action of

the saliva is arrested. In the small intestine, however the pancreatic juice takes up the work again ; and indeed by far the greater part of the starch which we eat i digested, that is, changed into sugar, by the action of thi juice.

Nor is this all, for, in addition to the above, the alkalin pancreatic juice has a powerful effect on proteids ver similar to that exerted by the acid gastric juice ; it con verts them into peptones, and the peptones so produce do not differ materially from the peptones resulting fro gastric digestion. At the same time a variable amount leucine and tyrosine make their appearance as the resu of the further action of pancreatic juice on the firs formed peptones.

Hence it appears that, while in the mouth carb hydrates only, and in the stomach proteids only, a digested, in the intestine all three kinds of food-stuff proteids, fats, and carbohydrates, are either completel dissolved and made diffusible or minutely subdivided, an so prepared for their passage into the vessels.

As the food is thrust along the small intestines by th grasping action of the peristaltic contractions, the digeste matter which it contains is absorbed, that is, passes awa from the interior of the intestine into the blood-vesse and lacteals lying in the intestinal walls.

All the way down the small intestines, the proteid carbohydrates, and fats of a meal are being dissolved freely divided, or otherwise changed, and passing awa into the lacteals or blood-vessels. So that, by the tim the contents of the intestine have reached the ileo-cæc valve, a great deal of the nutritious matter has bee removed. Still, even in the large intestine, some nutr tious matter has still to be acted upon ; and we find tha in the cæcum and commencement of the large intestin changes are taking place, apparently somewhat of th nature of fermentation, whereby the contents become aci But these changes do not appear to be brought abo

ny soluble ferments secreted by the walls of this stine ; on the contrary they are largely the result of activity of certain minute organisms or organised ents (Bacteria, &c.).

herbivora a considerable quantity of the cellulose cat does not reappear in the fæces and a small nt may be digested in man. This digestion of lose probably takes place in the large intestine and ought about by the action of micro-organisms.

ne marked feature of the changes undergone in the e intestine is the rapid absorption of water. Whereas he small intestine, the amount of fluid secreted into canal about equals that which is removed by absorp-, so that the contents at the ileo-cæcal valve are ut as fluid as they are in the duodenum ; in the large stine on the contrary, especially in its later portions, contents become less and less fluid. At the same e a characteristic odour and colour are developed, and remains of the food, now consisting either of un-estible material, or of material which has escaped the on of the several digestive juices, or withstood their uence, gradually assume the characters of fæces.

7. Absorption from the Intestines.—A great deal the absorption takes place in the small intestine ough the process is continued on in the large intestine), there can be no doubt that it is largely effected by ns of the villi. Each villus, as we have seen (p. 255), overed by a layer of epithelium, and contains in the tre a lacteal radicle, between which and the epithelium a network of capillary blood-vessels embedded in a icate tissue. Now in some way or other, not even yet roughly understood, the majority of the minute par-es of the finely divided, emulsified fat, pass through cells of the epithelium, past the capillary blood-sels, into the central lacteal radicle ; so that, after a y meal, these lacteal radicles of the villi become filled h fat. The lacteal radicle is continuous with the

interior of the lymphatic vessels which ramify in the walls of the intestine, and which pass into the larger lymphatic vessels running along the mesentery towards the thoracic duct. Into these vessels the finely divided fat passes from the lacteal radicle of the villus, and, mixing with the ordinary lymph contained in these vessels, gives their contents a white, milky appearance. Lymph thus white and milky from the admixture of a large quantity of finely divided fat is called chyle ; and this white chyle may after a meal be traced along the lymphatics of the mesentery to the thoracic duct, and along the whole course of that vessel to its junction with the venous system. After a meal, in fact, this vessel is continually pouring into the blood a large quantity of chyle, *i.e.* of lymph made white and milky by the admixture of fats drawn from the villi of the small intestine.

The absorption of fat by the epithelial cells of the villi is a process which is as yet not thoroughly understood ; but it must depend on some specific action of the cells in virtue of the fact that they are living things. It cannot be explained by reference to the merely chemical and physical condition of the fat ; but the physical state of minute subdivision to which fats are reduced in the intestine of course serves to bring the fat within the grasp of the cells.

In the case of the proteids and carbohydrates, the result of digestion has been to produce a solution of peptones and sugars which are extremely soluble and highly diffusible. Now we know that if such a solution is separated by a thin membrane from a solution of ordinary non-diffusible proteids, there would be a rapid transmission of the diffusible substances through and across the membrane. The conditions necessary for such a process are evidently present in the intestines where the solution in its interior is separated by what is practically a thin membrane from the (albuminous) blood in the capillaries just below the epithelial cells. It is thus very

ting to suppose that the absorption of peptones and s (also of salts) is the result of their diffusibility and e conditions to which they are exposed. And indeed *n certain limits* this view is correct. But it does not ny means explain the whole process. For if sub- es of differing diffusibilities be placed in the intestines ot found that the most diffusible substance is neces- absorbed the fastest. In fact we find that the ls of the absorption are in many ways so peculiar we must again, as in the case of the fats, look to the epithelial cells of the villi as determining and com- ly controlling the process, which is thus partly ical but chiefly due to the special activity of cells.

he fats pass, as already stated, into the lacteals and ce through the lymphatic vessels and thoracic duct the blood. Peptones and sugar, on the other hand, ear to be taken up by the capillary blood-vessels of villus, so that very little if any of them gets to the al radicle. From the capillaries of the villi the pep- s and sugar are then carried along the *portal vein* to liver, where they probably undergo some further ge. So that while the fat, though it gets for the t part into the general blood current by a round- t way, viz., by the lymphatics, reaches the blood, r as we know, very little changed, the peptones and rs on the other hand, though also taking a roundabout se, viz., by the liver, are probably altered before they thrown into the general blood stream ; for the portal l in which they are carried is acted upon by the liver re it flows through the hepatic vein into the general us system. But concerning both the process of rption itself and the changes undergone by the rbed products before they reach the heart, ready to istributed all over the body, we have probably much to learn.

Part II.—Food and Nutrition.

1. Some Aspects of Nutrition. — The digestive changes which mixed food undergoes in the alimentary canal prepares the food-stuffs, of which it is composed, for distribution as their food to the various tissues of the body. Entering the tissues, the food-stuffs provide, by the oxidational changes which they undergo, the energy which the body expends as heat and mechanical work, and at the same time they make good the waste of substance which results from their oxidation. While being in this way metabolised [1] or worked through the tissues, the food-stuffs may give rise incidentally to changes in the composition of any individual tissue or of a group of tissues, and hence of the body as a whole. These changes depend not merely upon the total amount of mixed food supplied to the body but more particularly upon the relative amounts of each kind of food-stuff which is present in and goes to make up that variable total amount of food. Thus we have the phenomena of starvation as an extreme instance of the effect of variation in the amount of food given ; and the special storage of glycogen (p. 216), and of fat are obvious instances of the effects of individual food-stuffs. The consideration of the possibilities thus indicated provides some of the problems of nutrition. But nutrition has also to deal with the quantitative relationships between the amount of food supplied and the amount of waste excreted ; to strike a balance between the two and to draw conclusions from the balance-sheet as to how the business of the body is being carried on. Further, since food not only repairs waste but also provides energy, the balance-sheet must take into account how much total energy is supplied in

[1] See note on p. 188.

food and how this available income is expended as
at and work.

2. **Some Statistics of Nutrition.** — The average
ight of a healthy full-grown man may be taken as 70
grammes (154 pounds). Such a body is made up, in
and numbers, as follows :—

Muscles and Tendons	41 per cent.
Skeleton	16 ,,
Skin	7 ,,
Fat	18 ,,
Brain	2 ,,
Thoracic viscera	2 ,,
Abdominal viscera	7 ,,
Blood[1]	7 ,,
	100 ,,

The waste which this body excretes and its distribution
nong the chief excretory organs is shown in the table on
e following page, in which the "water and other
tters" represent the total waste.

The "other matter" from the lungs is chiefly carbonic
d, in which the larger part of the carbon is excreted,
nging with it nearly all the oxygen originally taken in
the lungs. From the kidneys it includes urea, which
ntains nearly the whole of the nitrogen excreted,
ether with some 25 grammes (nearly 1 oz.) of inorganic
ts. From the skin the "other matter" is a small
ount of salts and some carbonic acid, and in the fæces
ncludes some 5 grammes of salts. The total output of

[1] The total amount of blood in the body is about 5 litres or rather
e than a gallon, and may be taken as being usually about $\frac{1}{13}$ or $\frac{1}{14}$ of
weight of the body.

	Water and **other Matters** which contain **Nitrogen** and **Carbon.**			
Lungs ...	320 grammes (11 oz. or say ½ pint)	778 grammes (27 oz.)	.....	225 grammes (8 oz.)
Kidneys ...	1,500 grammes (53 oz. or say 2½ pints)	65 grammes (2½ oz.) ...	17 grammes (255 grains)..	10 grammes (150 grains)
Skin	650 grammes (23 oz. or say 1 pint) .	45 grammes (1½ oz.)	.....	7 grammes (100 grains)
Fæces	130 grammes (4 oz.)	52 grammes (say 2 oz.)	3 grammes (45 grains) ...	30 grammes (450 grains)
	2,600 grammes (6 lbs. or 4½ pints)	940 grammes (2 lbs.)	20 grammes (¾ oz.)	272 grammes (9½ oz.)

ts from the body is thus about 30 grammes (or rather
re than 1 oz.).

This daily loss has to be made good by the new food
plied. But in calculating the amount of material
essary to replace the waste, we need only turn our
ntion to the nitrogen and the carbon, for the water
t represents almost entirely water taken as drink or in
food, although a small amount comes from the oxida-
n of the hydrogen of the food ; the oxygen is derived
m the air, and the salts are largely, though not entirely,
roduced as salts with the food.

The daily waste of nitrogen and carbon may be taken
round numbers as about 20 grammes (300 grains) of
e former and 270 grammes (or about $9\frac{1}{2}$ oz.) of the latter.
e nitrogen necessary to make good this loss can only be
tained from proteids.

No substance can serve permanently for food—that is
say, can prevent loss of weight and change in the general
mposition of the body—unless it contains a certain
nount of proteid matter in the shape of albumin, casein,
., &c., while, on the other hand, any substance which
ntains proteid matter in a readily assimilable shape, is
mpetent to act as a permanent vital food-stuff.

The human body, as we have seen, contains a large
antity of proteid matter in one or other of the forms
ich have been enumerated ; and, therefore, it turns out
be an indispensable condition, that every substance
ich is to serve permanently as food, must contain a
fficient quantity of the most important and complex
mponent of the body ready made. It must also con-
n a sufficient quantity of the mineral ingredients which
e required. Whether or no it contains either fats or
bo-hydrates, or both, its essential power of support-
g the life and maintaining the weight and composition
the body remains unchanged.

The necessity of constantly renewing the supply of
oteid matter arises from the circumstance that whether

the body is fed or not, a breaking down of proteid material is continually going on, giving rise to a constant nitrogenous waste, which leaves the body in the form of urea. Now, this nitrogeneous waste, coming from the breaking down of proteid material, can only be met by fresh proteid material being supplied. If proteid matter be not supplied, the body must needs waste, because there is nothing in the food competent to make good the nitrogeneous loss.

On the other hand, if proteid matter be supplied, there can be no absolute necessity for any other but the mineral food-stuffs, because proteid matter contains carbon and hydrogen in abundance, and hence is competent to make good not only the breaking down which is indicated by the nitrogenous loss, but also that which is indicated by the other great products of waste, carbonic acid and water.

In fact, the final results of the oxidation of proteid matters are carbonic acid, water, and ammonia; and these, as we have seen, are the final shapes of the waste products of the human economy.

Proteids contain in round numbers about 15 per cent. of nitrogen and 53 per cent. of carbon, so that the 20 grammes of nitrogen might be obtained from 130 grammes of proteid, which would at the same time introduce about 70 grammes of carbon. But the daily waste of carbon is (about) 270 grammes, thus some 200 grammes of carbon are still required to balance the excess in the excreta. This additional amount of carbon may be obtained from either fats or carbohydrates, but preferably from a mixture of the two. Now fats contain 80 per cent. of carbon, and carbohydrates contain 40 per cent.; thus the desired amount of extra carbon may be obtained by adding to the 130 grammes of proteid, about 50 grammes of fats which contain 40 grammes of carbon, and 400 grammes of carbohydrates which contain 160 grammes of carbon. Adding to these 30 grammes of inorganic salts

2,300 grammes of water the total waste is about
ced thus :—

		Nitrogen.	Carbon.
130 grammes	(4½ oz.) contain	20 grammes (¾ oz.)	70 grammes (2½ oz.)
50 ,,	(2 oz.) ,,	———	40 ,, (1½ oz.)
400 ,,	(14 oz.) ,,	———	160 ,, (5½ oz.)
30 ,,	(1 oz.) ,,	———	———
300 ,,	(4 pints) ,,	———	———
910 grammes		20 grammes	270 grammes (9½ oz.)

ods as previously explained (p. 224) never consist,
pt perhaps in the case of fats and oils, of one kind of
-stuff only ; each article of food contains at most an
ss of some one kind of food-stuff, and no two foods
exactly alike. Hence the selection of such foods as
supply the amount of proteids, fats, and carbo-
rates required by the above statement opens up the
ibility of an almost indefinite choice. But the
position of the more commonly used articles of food
egards the amounts of the several kinds of food-stuffs
contain, has been very carefully determined, so that
may now proceed to select a meal such as will give us
desired quantities of proteids, fats, and carbohydrates.
uppose, for instance, that we select lean meat, bread,
toes, milk, and fat, such as butter or dripping, as our
. We may obtain all that we require from the
unts of each food shown in the table on the following
e.

he amounts of the several foods shown in the above
e suffice to cover the waste shown in the table on p. 268
constitute what is ordinarily known as a diet. But the
thus given are to be taken rather as an illustration
ow the balance-sheet between food and waste is drawn
than as an example of exactly what a man ought to
n the way of food. As already pointed out, foods are
y, and vary in the relative amounts of the several
-stuffs they contain, so that it is possible to draw up

Quantity.	*Kind of Food.*	*Contains*	*Provides* Proteids.	Fats.	Carbohydrates.
230 grammes (or ½ lb.)	Very lean meat	25 per cent. proteids	58 grammes	—	—
480 grammes (or say 1 lb.)	Bread	8 per cent. proteids; 50 per cent. carbohydrates	39 ,,	—	240 grammes
660 grammes (or say 1½ lb.)	Potatoes	2 per cent. proteids; 21 per cent. carbohydrates	13 ,,	—	140 ,,
500 grammes (or say ¾ pint)	Milk	4 per cent. proteids; 4 per cent. fats; 4 per cent. carbohydrates	20 ,,	20 grammes	20 ,,
30 grammes (or say 1 oz.)	Fats	100 per cent. fats	—	30 ,,	—
2,300 grammes (or say 4 pints)	Water	—	—	—	—
			130 grammes	50 grammes	400 grammes

y such tables all satisfying the condition of covering laily loss of 20 grammes of nitrogen and about 270 or grammes of carbon.

n drawing up such a table of diet the question of cost t also not be forgotten, as in the case of fixing the for soldiers or prisoners. Thus, for instance, it costs e to obtain the requisite amount of carbon from fat from sugar or starch. Moreover, the value of a diet nds also on the ease with which its constituents can digested and utilised. Mere chemical analysis is itself a very insufficient guide as to the useful- and nutritive value of an article of food. A stance to be nutritious must not only contain e or other of the various food-stuffs, but contain n in an available, that is a digestible, form. A e of beef-steak is far more nourishing than a quantity ease pudding containing even a larger proportion of eid material, because the former is far more digestible the latter; and a small piece of dry hard cheese, ugh of high nutritive value as judged by mere chemical lysis, will not satisfy the more subtle criticism of the nach.

. **The Economy of a Mixed Diet.**—The body, as we e repeatedly pointed out, cannot obtain the nitrogen equires from any source other than the ready-made eids. Hence in the absence of these from the food of animal it must sooner or later die from what is known **nitrogen starvation.**

n this case, and still more in that of an animal deprived ital food altogether, the organism, so long as it con- ues to live, feeds upon itself. In the former case, all processes involving a loss of nitrogen, in the latter, the processes leading to the appearance of all the eral waste products, are necessarily carried on at the ense of its own body; whence it has been rightly ugh observed that a starving sheep is as much a car- ore as a lion. *Proteid is thus the essential element of*

all food, and since it contains carbon as well as nitrogen it may suffice, under certain circumstances, to maintain the body ; but it is a very disadvantageous and uneconomical food-stuff when taken by itself.

Albumin, which may be taken as a type of the proteids, contains about 53 parts of carbon and 15 of nitrogen in 100 parts. If a man were to be fed on white of egg, therefore, he would take in, speaking roughly, 3½ parts of carbon for every part of nitrogen.

But we have seen that a healthy, full-grown man, keeping up his weight and heat, and taking a fair amount of exercise, eliminates per diem 270 to 300 grammes of carbon to only 20 grammes of nitrogen, or, roughly, only needs one-thirteenth to one-fifteenth as much nitrogen as carbon. However, if he is to get his 270 grammes of carbon out of albumin, he must eat 500 grammes of that substance. But 500 grammes of albumin contain 75 grammes of nitrogen, or nearly four times as much as he wants.

To put the case in another way, it takes about four pounds (1,800 grammes) of fatless meat (which generally contains about one-fourth its weight of dry solid proteids) to yield the necessary amount of carbon, whereas one pound (453 grammes) will furnish all the nitrogen that is required.

Thus a man confined to a purely proteid diet must eat an excessive quantity of it in order to obtain the amount of carbon he requires. This not only involves a great amount of physiological labour in comminuting the food and a great expenditure of power and time in dissolving and absorbing it, but throws a great quantity of wholly profitless labour upon those excretory organs, which have to get rid of the nitrogenous matter, three-fourths of which, as we have seen, is superfluous.

Unproductive labour is as much to be avoided in physiological as in political economy ; and it is quite possible that an animal fed with perfectly nutritious proteid matter

ıld die of starvation; the loss of power in various
ations required for its assimilation overbalancing the
; or the time occupied in their performance being
great to permit waste to be repaired with sufficient
lity. The body, under these circumstances, falls into
ondition of a merchant who has abundant assets, but
cannot get in his debts in time to meet his creditors.
iese considerations lead us to the physiological justi-
ion of the universal practice of mankind in adopting a
ed diet, in which proteids are mixed either with fats
ith carbohydrates, or with both.

ats may be taken to contain about 80 per cent. of
on, and carbohydrates about 40 per cent. Now it has
n seen that there is enough nitrogen to supply the
e of that substance per diem, in a healthy man, in
grammes (a pound) of fatless meat which also contains
grammes (1,000 grains) of carbon, leaving a deficit of
grammes (3,000 grains) of carbon; 250 grammes (say
a pound) of fat, or 500 grammes (rather more than
ound) of sugar, will supply this quantity of carbon.

everal apparently simple articles of food constitute
ixed diet in themselves. Thus butcher's meat com-
ly contains from 30 to 50 per cent. of fat. Bread,
the other hand, contains the proteid gluten, and the
ohydrates, starch and sugar, with minute quantities
at. But from the proportion in which these proteid
other constituents exist in these substances, they are
her, taken alone, such physiologically economical
s as they are when combined in the proportion of
t 200 to 75, or two pounds of bread to three-quarters
pound of meat per diem.

here is one largely consumed article of food which is
merely composed of all the various food-stuffs requisite
rovide a mixed diet, but contains these substances in
relative amounts most suitable for affording an
omical diet as regards the proportion of the nitrogen
e carbon. This food is **milk**. Milk consists chiefly

of water (86 p. c.) in which proteids, casein and some albumin, are dissolved, as also a carbohydrate, milk-sugar or lactose, and inorganic salts such as chlorides and phosphates of sodium, potassium and calcium. The fat present in milk is emulsified or suspended in the water in the form of extremely minute globules, and the white appearance presented by milk is due to the great amount of light reflected from these minute particles of fat.

4. The Effects of the several Food-stuffs.—When some proteid food is given to an animal, such as a dog, which has been previously starved, the larger part of the nitrogen given in the proteid is not retained in the body but is excreted almost immediately. If another larger meal of proteid be given the amount of nitrogen excreted is still further increased, less and less being retained in the body. By proceeding in this way it is possible to increase the excretion of nitrogen to such an extent that it ultimately becomes equal to the amount administered in the food : the animal is then said to be in "nitrogenous equilibrium." Such are the facts, and their meaning is obvious. The *proteid-food stirs up the nitrogenous metabolism of the body* and stimulates it to an increased activity. But this effect is not confined to the nitrogenous metabolism alone, for if the output of carbonic acid and the corresponding intake of oxygen be measured during the above experiment, they are both found to be considerably above the average. Hence *proteid food also stimulates the non-nitrogenous metabolism of the body* and thus leads to an increased waste of all kinds. This fact is indeed made use of for the treatment of obesity by dieting, as in the Banting "cure," in which the carbohydrates and fat in the food are reduced as far as possible and large amounts of proteid are given.

The effects of carbohydrates and fats as foods cannot be studied by feeding an animal with these alone, as is possible with proteids. But this difficulty may be got over by administering a small, *fixed* quantity of protei

n a *variable* amount of either carbohydrate or fat. In case it is found that an increase of the carbohydrate od very soon leads to the laying on of fat; and this responds to the everyday experience which is frequently bodied in the expression "sugar is fattening." At same time analysis of the liver shows that a large unt of *glycogen is stored up* in it, as previously exined (p. 216).

f fats be given in increasing quantity they also finally to a laying on of fat, but by no means so readily as s an increase of carbohydrates. At the same time, storage of glycogen is observed in the liver. Fats are refore not as fattening as might at first sight have been pected.

We have already mentioned **gelatin** as a food-stuff ich consists of the same four elements as are present proteids and in somewhat similar proportions. But nitrogen in gelatin cannot permanently replace that a proteid for the repair of nitrogenous waste. An mal fed with gelatin dies ultimately of "nitrogen rvation," though not as soon as it would without this nstituent of food. This seems to imply that the rogen of gelatin can for a time and to a certain extent e the place of the nitrogen of proteids; and this view borne out by the fact that "nitrogenous equirium" can be attained quite readily when a considerable ount of the proteid required in the experiment is reced by gelatin. Thus gelatin reduces the waste of the dy and, so far, may be a useful article of food.

The **salts** which leave the body are largely the salts ich were introduced in the food. It might therefore first sight appear that they are merely unavoidable nstituents of food which are largely passed without nge through the body. But this is not the case. In ne way or other the salts of food play an essential t in directing the metabolism taking place in the sues. Thus animals fed with an abundance of food,

which has however been freed as far as possible from salts, soon die with symptoms of defective nutrition, accompanied by paralysis and convulsions.

When an animal is deprived of all food whatsoever, it begins to feed on its own tissues. Thus up to the day of its death from starvation there is an output of urea and of carbonic acid, though in amounts less than when food is being taken. The loss of tissue-substance thus produced affects the several tissues to different extents ; but without entering into details we may simply point out that the master-tissues suffer least, in the obvious effort to prolong life to the utmost. Thus the brain and spinal cord are almost unaltered at death, and the blood and the muscular tissue of the heart also lose but little as compared with the fat and the skeletal muscles on which the body is now chiefly living.

5. The Erroneous Division of Food-stuffs into Heat-producers and Tissue-formers. -Food-stuffs have been divided into *heat-producers* and *tissue-formers* - the carbohydrates and fats constituting the former division, the proteids the latter. But this is a very misleading, and indeed erroneous classification, inasmuch as it implies, on the one hand, that the oxidation of the proteids does not develop heat ; and, on the other, that the carbohydrates and fats in being oxidised, subserve only the production of heat.

Undoubtedly proteids are *tissue-formers*, inasmuch as no tissue can be produced without them ; for all the tissues are nitrogenous, some containing a large and others a small quantity of nitrogen, and proteids are the only nitrogenous food-stuffs ; they alone can supply the nitrogenous elements of the tissues. But there is reason to think that the fats and carbohydrates taken as food may also be directly built up into the tissues.

Moreover if the proteids alone are the tissue-formers then the energy set free during the contracting activity of the pre-eminently nitrogenous muscles ought to come

the metabolism of their proteids. But this is not
ld to be the case, for even the most violent muscular
cise does not lead to any increased output of nitro-
us waste which is in the least proportionate to
work being done. On the other hand exercise at
, and largely, increases the excretion of carbonic acid,
extent which may be five times as great as during
; that is to say, the non-nitrogenous part of the
ne seems to be used up more quickly than the nitro-
ous part; and the consumption of this particular
stituent of the muscular substance may be made good
non-nitrogenous food, by fats or carbohydrates.
On the other hand, proteids must be regarded as heat-
ducers also. For if oxidation be, as has been suggested,
gely confined to the tissues, though in some tissues, as
muscles, the non-nitrogenous part seems to be most
idly changed, yet the nitrogenous part, supplied by the
teids, is sooner or later oxidised, and in being oxi-
ed must give rise to heat.
As soon as the elements of the food, in fact, get into
tissues, the distinction between the two classes is
; both form tissues, and both supply heat.
f it is worth while to make a special classification of
vital food-stuffs at all, it appears desirable to dis-
guish the *essential* food-stuffs, or proteids, from the
essory food-stuffs, or fats and carbohydrates—the
ner alone being, in the nature of things, necessary to
, while the latter, however important, are not abso-
ely necessary.

. **The Income and Expenditure of Energy.**—It is
te certain that nine-tenths of the dry, solid food which
aken into the body, sooner or later leaves it in the
pe of carbonic acid, water, and urea; and it is also
ain not only that the compounds which leave the
y are more highly oxidised than those which enter it, but
all the oxygen taken into the blood by the lungs is
ried away out of the body in the various waste products.

The intermediate stages of this conversion are, however, by no means so clear. It is highly probable that all the food-stuffs which pass from the alimentary canal into the blood, be they proteids, or fats, or carbohydrates, become part and parcel of some tissue or other (muscle, nervous tissue, glandular tissue, and the like), before they are oxidised; that indeed it is as constituent elements of some tissue or other that they suffer oxidation, and that the amount of oxidation going on in the blood is very small.

In the course of its oxidation, the food not only supplies the energy which the body expends in doing work, but also the energy which, as we have seen, the body loses as heat. The oxidation of the food is indeed the ultimate source of the heat of our bodies, all other causes being of little moment. About this there can be no doubt, and it is further probable that the oxidation which thus gives rise to heat is not the oxidation of the elements of the food as they are carried about in the blood, but the oxidation of the tissues, more especially the muscles, into which the food-stuffs have been built up, and of which they have become an integral part.

The oxidation of the tissues, which are themselves built up out of food, and hence ultimately the oxidation of the food itself, thus provides for the energy expended as muscular work and as heat. Now the amount of mechanical work a man does may be determined with no great difficulty, whether we calculate it as work done in walking or in turning some machine or in some other effort which results in overcoming a resistance. This work is measured in terms of the resistance overcome, or weight lifted, multiplied by the height through which it is raised. Thus we speak of the work done in lifting one pound through the height of one foot as a foot-pound; or using the metric system and taking a kilogramme (2·2 lbs.) and a meter (39·37 inches) as the units of weight and distance, we call the unit of work a kilogramme-meter, equal to 7·24 foot-pounds. Using the

r unit we may say that a good day's work is about
00 kilogramme-meters.

e unit of heat is the amount of heat required to
the temperature of one pound of water through
. Now, as is seen in all ordinary engines, heat can
ork ; and it is found that one unit of heat can do
oot-pounds of work. This is called the "mechanical
valent of heat." In the metric system the unit
mes the amount of heat required to raise the
perature of one gramme (15·4 grains) of water through
. This is called a **calorie**, and the mechanical
valent of heat is now 424 gramme-meters. Using
e data we can readily convert heat into its equivalent
ork or *vice versâ*.

he measurement of the amount of heat given off by
body is by no means easy, and the sources of error
considerable. But allowing for these a rough deter-
ation may be made, and the heat thus measured may
alculated as work by using the mechanical equivalent
eat and the result added to the actual work done as
k. The outcome of this calculation shows that of the
l energy expended by the body about one-sixth is put
as work and five-sixths as heat. Finally we find that
average total output of energy as work and heat (cal-
ted as work) may be taken as about 1,000,000
gramme-meters.

We may now consider how far this expenditure is met
he income of energy in food. When a substance is
pletely burnt, *i.e.* oxidised, to water and carbonic
, a certain amount of heat is produced which can be
sured. Thus it is possible to determine how much
is produced by the complete combustion of one
me of each of the food-stuffs, proteids, fats and
ohydrates. The result obtained is as follows :—

1 gramme	of	proteid	gives	5,700 calories.
1 ,,	,,	fat	,,	9,500 ,,
1 ,,	,,	carbohydrate	,,	4,000 ,,

Now this must also be the amount of heat produced by the same quantity of each of these food-stuffs during their oxidation in the animal body. In the case of the proteid some deduction has to be made because the proteids are not completely oxidised ; the nitrogen they contain leaves the body as urea, which is still capable of undergoing further oxidation to water, nitrogen, and carbonic acid. One gramme of proteid gives rise to about $\frac{1}{3}$ gramme of urea, and the complete combustion of this amount of urea gives rise to 844 calories. Hence, deducting these from the 5,700 gives us about 4,800 calories, which we may take as being the *physiologically available* heat of combustion of one gramme of proteid. If now we apply these values to the diet given on p. 271 we find that :—

130	grammes	of proteid	give	624,000	calories.
50	,,	,, fats	,,	475,000	,,
400	,,	,, carbohydrate	,,	1,600,000	,,
				2,699,000	

If now we take the mechanical equivalent of this heat we find it works out as 1,144,376 kilogramme-meters. Hence the energy available by the oxidation in the body of this particular diet is more than sufficient to balance the total amount which we saw was expended.

LESSON VII

MOTION AND LOCOMOTION

The Source of Active Power and the Organs of tion.—In the preceding Lessons the manner in which incomings of the human body are converted into its goings has been explained. It has been seen that new ter, in the form of vital and mineral food, is constantly ropriated by the body, to make up for the loss of matter, which is as constantly going on in the shape, fly, of carbonic acid, urea, and water, the formation of waste being the outcome of oxidation accompanied by eration of energy.

he vital foods are derived directly, or indirectly, from vegetable world: and the products of waste either such compounds as abound in the mineral world, or ediately decompose into them. Consequently, the an body is the centre of a stream of matter which incessantly from the vegetable and mineral worlds the mineral world again. It may be compared to ddy in a river, which may retain its shape for an finite length of time, though no one particle of the r of the stream remains in it for more than a brief od.

ut there is this peculiarity about the human eddy, a large portion of the particles of matter which flow it have a much more complex composition than the cles which flow out of it. To speak in what is not ether a metaphor, the atoms enter the body for the

most part, piled up into large heaps, and tumble down into small heaps before they leave it. The energy which they set free in this tumbling down, is the source of the active powers of the organism.

These active powers are chiefly manifested in the form of motion—movement, that is, either of part of the body, or of the body as a whole, which last is termed *locomotion*.

The organs which produce total or partial movements of the human body are of three kinds: *cells exhibiting amœboid movements*, *cilia*, and *muscles*.

FIG. 84.—COLUMNAR CILIATED EPITHELIUM CELLS FROM THE HUMAN NASAL MEMBRANE.

Magnified 300 diameters. (Sharpey.)

The amœboid movements of the white corpuscles of the blood have been already described, and it is probable that similar movements are performed by many other simple cells of the body in various regions.

The amount of movement to which each cell is thus capable of giving rise may appear perfectly insignificant; nevertheless, there are reasons for thinking that these amœboid movements are of great importance to the economy, and may under certain circumstances be followed by very notable consequences.

2. Ciliated Epithelium and Action of Cilia.—Cilia are filaments of extremely small size, attached by their bases to, and indeed growing out from, the free surfaces of certain epithelial cells; there being in most instances very many (thirty for instance), but, in some cases, only a few cilia on each cell (Figs. 40, 84). In some of the lower animals, cells may be found possessing only a single cilium. They are in incessant waving motion, so long as life persists in them. Their most common form of movement is that each cilium is suddenly bent upon itself

nes sickle-shaped instead of straight, and then more
ly straightens again, both movements, however, being
mely rapid and repeated about ten times or more
second. These two movements are of course
gonistic ; the bending drives the water or fluid in which
lium is placed in one direction, while the straightening
s it back again. Inasmuch, however, as the bending
ch more rapid than the straightening, the force ex-
ed on the water in the former movement is greater
in the latter. The total effect of the double move-
: therefore is to drive the fluid in the direction towards
h the cilium is bent : that is, of course, if the cell on
h the cilia are placed is fixed. If the cell be floating
, the effect is to drive or row the cell backwards ; for
cilia may continue their movements even for some
after the epithelial cell, with which they are connected,
tached from the body. And not only do the move-
ts of the cilia thus go on independently of the rest of
body, but they appear not to be controlled by the action
he nervous system. Each cilium is comparable to one
he mobile processes of a white corpuscle. A ciliated
differs from an amœboid cell in that its contractile
esses are permanent, have a definite shape, and are
lised in a particular part of the cell, and that the
ements of the processes are performed rhythmically
always in the same way. But the exact manner in
ch the movement of a cilium is brought about is not
et thoroughly understood.

lthough no other part of the body has any control
the cilia, and though, so far as we know, they have
direct communication with one another, yet their action
irected towards a common end—the cilia, which cover
nsive surfaces, all working in such a manner as to
ep whatever lies upon that surface in one and the
e direction. Thus, the cilia which are developed
n the epithelial cells, which line the greater part
the nasal cavities and the trachea, with its rami-

fications, tend to drive the mucus in which they work, outwards.

In addition to the air-passages, cilia are found, in the human body, in a few other localities ; but the part which they play in man is insignificant in comparison with their function in the lower animals, among many of which they become the chief organs of locomotion.

3. The Structure of Unstriated Muscle.—Unstriated (also called "plain" or "smooth") muscle occurs in the walls of the alimentary canal, the blood-vessels, the bladder, and other organs. It is composed of bands of fibres which are bound together by connective tissue carrying nerves and blood-vessels. The fibres are in reality elongated, flattened, spindle-shaped cells whose

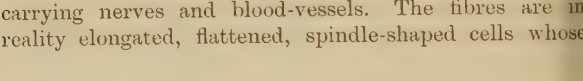


FIG. 85.—A FIBRE-CELL FROM THE PLAIN, NON-STRIATED MUSCULAR COAT OF THE INTESTINE.

f, fibre ; *n*, nucleus ; *p*, granular protoplasm around the nucleus.

length is about 50μ ($\frac{1}{500}$ inch) and width 6μ ($\frac{1}{4000}$ inch). Somewhere towards the middle of each cell there is an elongated oval or sometimes rod-shaped nucleus, surrounded by a small amount of granular protoplasm which is pointed at the ends of the nucleus.

The substance of the cell is clear and shows no transverse striations, although it often shows signs of a very fine longitudinal fibrillation. Each cell is said to be surrounded by an extremely delicate sheath, but as to this, opinions differ. A number of such fibre-cells are united together by a minute quantity of cement, or intercellular substance, into a thin flat band, and a number of such bands are bound together by connective tissue into larger bands or bundles. Each fibre is capable

ntracting, that is, of shortening and becoming at same time thicker.

The Structure of Striated Muscle.—Striated le is also made up of fibres, though the fibres are different from the fibres or fibre-cells of unstriated ie, and these fibres are again similarly bound up ner in various ways, by connective tissue which s the blood-vessels and nerves, so as to form cles of various shapes and sizes.[1] Each muscle us made up of (i) an external wrapping or **perisium**; this is a sheath of connective tissue from inner face of which partitions proceed and divide space which it incloses into a great number ngitudinally disposed compartments; (ii) the **muar fibres** which occupy these compartments; (iii) **vessels** which lie in the sheath and in the itions between the compartments, and thus surnd the muscular fibres without entering them; (iv) **motor nerves** which also at first lie in the sheath in the partitions between the compartments, but ch eventually enter into the muscular fibres.

he *perimysium* forms a complete envelope around muscle, which, when it is sufficiently strong to be ected off, is known as a **fascia**; at each end it ally terminates in dense connective tissue (**tendon**), ch becomes continuous with the bone or cartilage to ch the tendon is attached. The partitions given off n the inner surface of the perimysium form at first se compartments, inclosing large bundles, each coning of a very great number of fibres. These large dles are again divided by somewhat finer connective ue partitions into smaller bundles, and these again still smaller ones, and so on, the smallest bundles of

t is necessary to distinguish "muscle" as an organ from "muscle" tissue. The biceps muscle (p. 304), for example, is an organ of a comted character, of which muscular tissue forms only the chief constit.

all being composed of a number of individual muscular fibres (Fig. 86). In this way the partitions become thinner and more delicate, until those which separate the chambers in which the individual muscular fibres are contained are reduced to little more than as much connective tissue as will hold the small nerves, arteries and veins and capillary networks together. As the perimysium consists of connective tissue, it may be destroyed by prolonged boiling in water. In fact, in "meat boiled to rags" we have muscles which have been

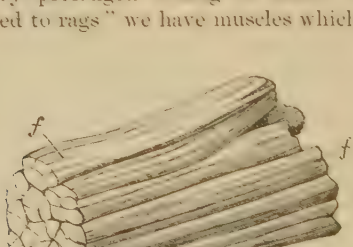


FIG. 86.—FASCICULI OF STRIATED MUSCLE CUT ACROSS.

Several fasciculi *f*, bound together into larger fasciculi to make up the muscle.

thus treated: the perimysial case is broken up, and the muscular fibres, but little attacked by boiling water, are readily separated from one another.

If a piece of muscle of a rabbit which has been thus boiled for many hours, is placed in a watch-glass with a little water, the muscular fibres may be easily teased out with needles and isolated. Such a fibre will be found to have a thickness of somewhere about 60μ ($\frac{1}{1000}$ inch) (they vary, however, a great deal), with a length of 30 or 40 millimetres, *i.e.*, about 1$\frac{1}{2}$ inch. It is a cylindroidal or polygonal solid rod, which either tapers or is bevelled off

nch end. By these it adheres to those on each side of
or, if it lies at the end of a series, to the tendon.
ie structure and properties of striated muscular tissue
ie histological sense means the structure and properties
iese fibres.
s we have already had occasion to remark, all tissues
ergo considerable alteration in passing from the living

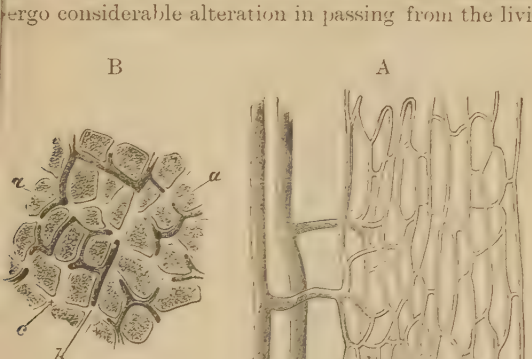


FIG. 87.—CAPILLARIES OF STRIATED MUSCLE.

Seen longitudinally. The width of the meshes corresponds to that of
ltimate fibre. *a*, small artery; *b*, small vein.
Transverse section of striated muscle. *a*, the cut ends of the ulti-
e fibres; *b*, capillaries filled with injection material; *c*, parts where
capillaries are absent or not filled.

he dead state, but, in the case of muscle, the changes
ch the tissue undergoes in dying, are of such a marked
racter that the structure of the dead tissue gives a false
ion of that of the living tissue.
living striated muscular fibre of a frog or a mammal
pale transparent rod composed of a soft, flexible,
tic substance, the lateral contours of which, when the

fibre is viewed out of the body, appear sharply defined, like those of a glass rod of the same size; but when the fibre is observed in the living body, bathed in the lymph which surrounds it, the outlines are not so sharply de-

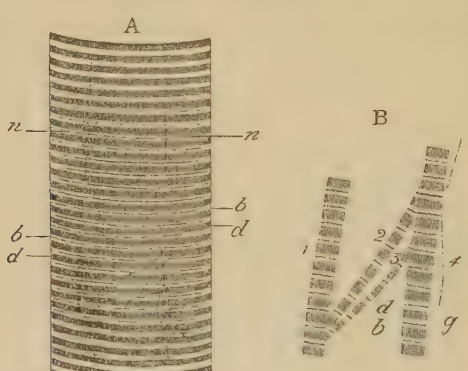


FIG. 88.—TO ILLUSTRATE THE STRUCTURE OF A STRIATED MUSCULAR FIBRE.

A. Part of a muscular fibre (of a frog) seen in a natural condition. *d*, dim bands; *b*, bright bands, with the granular line seen in many of them; *n*, nuclei and the granular protoplasm belonging to them, very dimly seen.

B. Portion of prepared mammalian muscular fibre teased out, showing longitudinal portions of variable (1, 2, 3, 4) thickness; 4 represents the finest portion (fibrilla) which could be obtained; *d*, dim bands; *b*, bright bands, in the midst of each of which is seen the granular line *g*.

fined. In neither case can any distinct line of demarcation between a superficial layer and a deeper substance be recognised. The fibre appears transversely striped, as if the clear glassy substance were, at regular intervals (Fig. 88, A, *d*), converted into ground glass, thus appearing dimmer. Each of these "dim bands" is about 2μ wide, and the clear space or "bright band" which separates every two dim bands is of about the same size,

nder ordinary circumstances somewhat narrower. a high power a very thin dark granular line equi-nt from each dim band is discernible in each bright . dividing the bright band into two. As these rances remain when the object glass is focused gh the whole thickness of the fibre, it follows that im bands, the granular lines, and the clear spaces on side of each granular line, represent the edges of ents of different optical characters, which regularly nate through the whole length of the fibre. Let the ssively thin segments, of which the thin granular represent the edges, be called *g*, the thicker, pellucid ents of which the bright bands on each side of a ular line represent the edges, B; and the thickest tly opaque segments of which the ground glass like bands are the edges, D. Then the structure of the may be represented by *D.B. g.B. D.B. g.B.* indefinitely ated, and one inch of length of fibre will contain t 30,000 such segments, or alternations of structure.

a perfectly unaltered living fibre the striated sub-ce presents hardly any sign of longitudinal striation; near to the surface of the fibre in mammalian muscle, gh at various points in the depth of the fibre in the cles of the frog, faint indications are to be observed he existence of cavities each filled by a nucleus, ounded by a small amount of protoplasm (Fig. 88, *n*).

s the muscular fibre dies it undergoes a rapid altera-:—(i) parallel longitudinal striæ, often less than 2μ rt, appear, in greater or less numbers until sometimes striated substance appears broken up into a mass of delicate fibres; (ii) the dim bands become much more que, and hence the transverse striation appears better ked, until the dim bands may appear like sharply ned discs; (iii) the nuclei acquire sharp irregular tours and become much more conspicuous, and (iv) ecially under certain circumstances and after particular

treatment, a thin superficial layer becomes sharply separated from the deeper substance of the fibre as a membrane of glassy transparency, the **sarcolemma**, which ensheathes the striated and fibrillated substance.

The bright bands and the granular lines, on the other hand, undergo little alteration.

Under very high powers each granular line looks like a number of minute granules lying side by side as an extremely thin plate, the margins of which are attached to the sarcolemma; it is often spoken of as *Krause's membrane*.

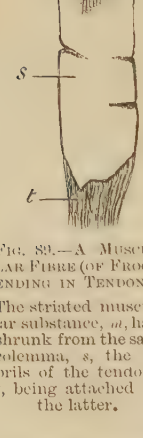


FIG. 89.—A MUSCULAR FIBRE (OF FROG) ENDING IN TENDON.

The striated muscular substance, *m*, has shrunk from the sarcolemma, *s*, the fibrils of the tendon, *t*, being attached to the latter.

If the sarcolemma of a dead fibre be torn with needles, the striated substance breaks up in different ways according to the treatment to which the fibre has been previously subjected. It may break up into discs, each of which contains a dim band. Or it may break up into fibrils, each of which presents the same segmentation as the whole fibre. These artificial fibrils vary much in thickness according to mode of preparation and the skill of the operator; they may sometimes be obtained of exceeding fineness (Fig. 88, B). Transverse sections of muscular fibre, which have been frozen while perfectly fresh, present minute close-set circular dots, which appear to represent the transverse sections of naturally existing longitudinal fibrils. These dots are known as **Cohnheim's areas**. If the muscle substance is really in this case unaltered the only possible interpretation of the fact is that the fibre is really made up of fibrils, and that these are invisible in the living muscle on account of their having the same refractive power as the interfibrillar sub-

e. But whether the finest artificial fibrils into which muscle may be broken up are identical with these rently natural fibrils, it is not at present certainly mined. In some cases the artificial fibrils seem ler than the natural ones, as if the latter, like the itself, were capable of longitudinal cleavage.

ese are the most important structural appearances nted by ordinary striated muscle. But it may er be noticed that the dim bands exert a powerful ence on polarised light. Hence when a piece of le is placed in the field of a polarising microscope the prisms are crossed so that the field is dark, these is appear bright. The granular lines have a similar very much less marked effect.

n the embryo the place of the adult tissue is occupied a mass of closely applied, undifferentiated nucleated s. As development proceeds, some of these cells are verted into the tissues of the perimysium, but others easing largely in size gradually elongate and take on form of more or less spindle-shaped rods or fibres. nwhile the nucleus of each cell repeatedly divides, thus each rod becomes provided with many nuclei, hat each fibre is really a multi-nucleate cell. Along n these changes the protoplasmic substance of the inal cell becomes, for the most part, converted into characteristically striated muscle substance, only a e remaining unaltered around each nucleus as a muscle uscle.

he many-nucleated cell thus changed into a muscular e is nourished by the fluid exuded from the adjacent llaries, and it may be said to respire, insomuch as its stance undergoes slow oxidation at the expense of the gen contained in that fluid, and gives off carbonic . It is, in fact, like the other elements of the tissues, rganism of a peculiar kind, having its life in itself, dependent for the permanent maintenance of that upon the condition of being associated with other

such elementary organisms, through the intermediation of which its temperature and its supply of nourishment are maintained.

The special property of a living muscular fibre, that which gives it its physiological importance, is its peculiar contractility. The body of a colourless blood corpuscle, as we have seen, is eminently contractile, insomuch as it undergoes incessant changes of form. But these changes take place at all points of its surface, and have no definite relation to the diameter of the corpuscle, while the contractility of the muscular fibre is manifested by a diminution in the length and a corresponding increase in the thickness of the fibre. · Moreover, under ordinary circumstances, the change of form is effected very rapidly, and only in consequence of the application of a stimulus.

When a contracting striated fibre is observed under the microscope all the bands become broader (across the fibre) and shorter (along the fibre) and thus more closely approximated. Some observers think that the clear bands are diminished in total bulk relatively to the dim bands ; but this is disputed by others. When the fibre relaxes again the bands return to their previous condition.

5. **The Chemistry of Muscle.**—If a muscle taken perfectly fresh from the body be cooled down with ice in order to keep it from undergoing change (just as was previously done with blood, p. 107) and subjected to considerable pressure it yields a fluid called **muscle plasma.** This remains fluid so long as it is kept adequately cooled, but *clots* spontaneously at ordinary temperatures. The clotting takes place in a way very similar to that already described for blood-plasma and results in the formation of a semi-solid gelatinous substance, called **myosin,** and a small amount of fluid, or **muscle-serum.** Myosin is a proteid and belongs to the same class of proteids as do the fibrinogen and paraglobulin of blood, namely the *globulins.* During the formation of myosin, the fluid, which when first squeezed out was

tly alkaline, becomes distinctly acid owing to the nation of an organic acid called **sarcolactic acid.** s longer or shorter time after death this clotting takes e in the body within the muscles themselves. They me more or less opaque, and, losing their previous icity, set into hard, rigid masses, which retain the which they possess when the clotting commences. ce the limbs become fixed in the position in which h found them, and the body passes into the condition what is termed the "death-stiffening," or **rigor ortis.** This stiffening is also accompanied by a change he chemical reaction of the muscle, for while living scle when tested with litmus is faintly alkaline or tral, at least when at rest, it becomes distinctly acid *rigor mortis* sets in. And it may be added that a ilar but slighter acidity is developed even in a living scle, when it contracts.

After the lapse of a certain time the coagulated matter uefies, and the muscles pass into a loose and flabby dition, which marks the commencement of putre-tion.

It has been observed that the sooner *rigor mortis* sets the sooner it is over ; and the later it commences, the ger it lasts. The greater the amount of muscular rtion and consequent exhaustion before death, the ner *rigor mortis* sets in.

Rigor mortis evidently presents some analogies with clotting of the blood, and the substance which is med within the fibre (myosin) is in many respects not like fibrin.

When a muscle is treated with dilute acids, such as drochloric acid, the myosin is changed into an entirely ferent kind of proteid, called **syntonin.** Before the ture of myosin was understood it was supposed that substance of a muscle was chiefly composed of tonin ; we now know that syntonin does not exist a muscle but is entirely a product of the action of

acids on the myosin. Besides myosin, muscle contains other varieties of proteid material about which we at present know little ; a variable quantity of fat ; certain inorganic saline matters, phosphates and potash being, as is the case in the red blood-corpuscles, in excess ; and a large number of substances existing in small quantities, and often classed together as "extractives." Some of these extractives contain nitrogen ; the most important of this class is **creatine**, a crystalline body which is supposed to be the chief form in which nitrogenous waste matter leaves the muscle on its way to become urea.

The other class of extractives contains bodies free from nitrogen, perhaps the most important of which are **sarcolactic acid** and **glycogen.**

Most muscles are of a deep, red colour ; this is due in part to the blood remaining in their vessels ; but only in part, for each fibre (into which no capillary enters) has a reddish colour of its own, like a blood-corpuscle but fainter. And this colour is probably due to the fibre possessing a small quantity of that same hæmoglobin in which the blood-corpuscles are so rich.

6. The Phenomena of Muscular Contraction.—Every fibre in a muscle has the property, under certain conditions, of shortening in length, while it increases correspondingly in width, so that the volume of the fibre remains unchanged. This property is called **muscular contractility**, and whenever, in virtue of this property, a muscle fibre contracts it tends *to bring its two ends closer together*. Since a muscle is made up of a collection of these fibres, when the fibres contract the muscle as a whole also contracts ; it becomes shorter and thicker, and brings its two ends closer together, along with whatever may be fastened to those ends. By this action the muscles lead to the *motion* of the parts to which they are attached and by these motions give rise to *locomotion*.

The condition which ordinarily determines the con-

ion of a muscular fibre is, the passage along the
e fibre, which is in close anatomical connection with
muscular fibre, of a **nervous impulse**, *i.e.*, of a
ular change in the substance of the nerve which is
gated from particle to particle along the fibre. The
fibre is thence called a **motor fibre**, because, by
fluence on a muscle, it becomes the indirect means
oducing motion (see Lesson XI.).

e phenomena of muscular contraction may be con-
ntly studied in the muscles from the calf of a frog's
which, since the frog is a "cold-blooded" animal,
ns its powers of contracting for some time after it is
ved from the body. This muscle is called the
trocnemius and may be dissected out so as to be
attached to a piece of the *femur* near the knee and to
nerve, the **sciatic**, which supplies it. This muscle
us taken out of the body is known as a *muscle-nerve*
aration (Fig. 90).

ne muscle may now be suspended by the femur and a
ht hung on to the tendon at its lower end, and then
e to contract by stimulating the sciatic nerve (see also
on XI.).

hen the nerve is stimulated by a stimulus which
as short a time as possible, as, for instance, by the
entary electric current often called an induction
k, the following changes take place in the muscle.

It becomes shorter and thicker, lifts the weight
hed to it and then relaxes, allowing the weight to
again. The shortening and relaxing take place very
dly, the whole process occupying rather more than
f a second.

) The muscle may be enclosed in a small chamber
made to contract several times. If now we examine
ir in the chamber in which this *excised* muscle has
contracting we cannot obtain satisfactory evidence
ny escape of carbonic acid from the muscle during
ontraction; if carbonic acid is produced it must be

retained within the muscle, presumably in the form of some simple chemical compound. That, however, the muscle *within the body* does give off carbonic acid during its contraction is clearly shown by the fact that the venous

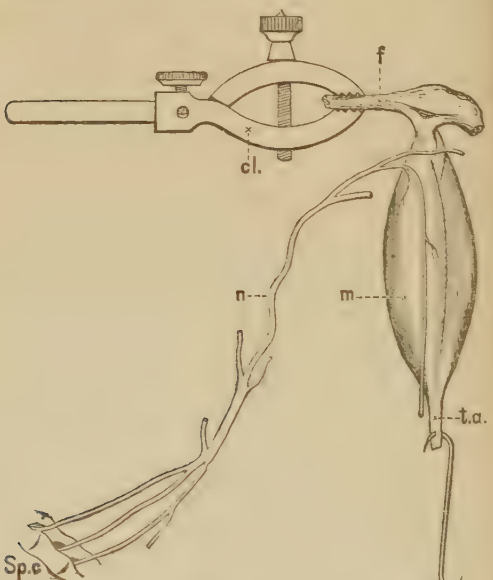


FIG. 90.—A MUSCLE NERVE PREPARATION.

m, the muscle, gastrocnemius of frog; *sp.c*, lower end of spinal column; *n*, the sciatic nerve, all the branches being cut away excepting that supplying the muscle; *f*, the femur; *cl*, a clamp to hold the femur; *t.a*, Achilles tendon.

blood coming from a contracting muscle contains relatively more carbonic acid than it does when the muscle is at rest. The substance of the muscle may at the same time have become faintly acid as tested by litmus paper. The acidity is due to sarcolactic acid.

.) The muscle becomes slightly warmer; this can be due to the fact that heat is formed during the raction. The rise of temperature is slight, but may ys be observed.

) The muscle undergoes certain electrical changes. ie moment of commencing contraction the muscle nes like a small battery cell, and can send an electric nt through a wire whose ends are suitably applied to urface of the muscle.[1]

e have already more than once insisted on the fact ll the tissues of the body are continually taking up en which they stow away in the form of some ound, since no oxygen can be extracted from them n air pump. In muscle this storage of oxygen leads instability of the contractile substance of which it is posed, so that when the appropriate stimulus is given this unstable substance undergoes a sudden decom- ion, almost explosive in its nature; and the energy free during the decomposition makes itself known ly as the work which the muscle can do in overcoming sistance and partly as heat. This decomposition ccompanied by an electrical disturbance and the arance of the products of decomposition.

The Tetanic Contraction of Muscles.—When rimenting with a muscle-nerve preparation, as in the eding section, it is easy to stimulate the nerve twice ich rapid succession that the second stimulus is given e the muscle is in a state of contraction resulting the first. In this case the muscle responds to the nd stimulus as well as to the first; in other words it racts still more while already contracting. The nd contraction takes place on top of the first, is er less in amount than the first, and is added on to first. If now a *rapidly successive series of stimuli* be

ee also Lesson XI., where the electrical changes of an active nerve, are essentially the same as those of a contracting muscle, are ibed in greater detail.

applied to the nerve, the muscle responds by an equally rapid series of contractions, each of which takes place before the preceding one is over; the whole series is thus added together, and the muscle remains in a state of *continued contraction* as long as the stimuli are continued, until exhaustion sets in. A prolonged contraction made up of such a series of single contractions superadded to each other is called a **tetanic contraction.** The acidity and heat which are developed at a single contraction become much more obvious during a continued tetanic contraction.

The voluntary contractions by which we execute the various movements of our body are in reality, in at all events nearly all cases, tetanic contractions, however short they may appear to be. Thus when we contract one of our muscles by an effort of the will it appears that a series of impulses is sent out in rapid succession from the spinal cord, perhaps at the rate of twelve or more in a second, to throw the muscle into prolonged contraction. By this means our control of the resulting movement is far greater than it would be if we were only able to execute single, short and sudden contractions such as result from sending a single impulse along the nerve going to the muscle.

8. The Various Kinds of Muscles.—Muscles may be conveniently divided into two groups, according to the manner in which the ends of their fibres are fastened into muscles not attached to solid levers, and muscles attached to solid levers.

Muscles not attached to solid Levers.—Under this head come the muscles which are appropriately called **hollow** muscles, inasmuch as they inclose a cavity or surround a space; and their contraction lessens the capacity of that cavity, or the extent of that space.

The muscular fibres of the heart, of the blood-vessels of the lymphatic vessels, of the alimentary canal, the urinary bladder, of the ducts of the glands,

ris of the eye, are so arranged as to form hollow
les.

the heart the muscular fibres which, though peculiar
striated, are arranged in an exceedingly complex
ner round the several cavities, and they contract,
have seen, in a definite order.

e iris of the eye is like a curtain, in the middle of
n is a circular hole. The muscular fibres are of the
th or unstriated kind (see p. 286), and they are
sed in two sets : one set radiating from the edges of
nole to the circumference of the curtain ; and the
set arranged in circles, concentrically with the aper-
The muscular fibres of each set contract suddenly
ogether, the radiating fibres necessarily enlarging the
the circular fibres diminishing it.

the alimentary canal the muscular fibres are also of
nstriated kind, and they are disposed in two layers ;
set of fibres being arranged parallel with the length of
ntestines, while the others are disposed circularly, or
r at right angles to the former.

has been stated above (p. 252), the contraction of
muscular fibres is successive ; that is to say, all the
ular fibres, in a given length of the intestines, do
ontract at once, but those at one end contract first,
he others follow them until the whole series have
acted. As the order of contraction is, naturally,
ys the same, from the upper towards the lower end,
ffect of this peristaltic contraction is, as we have seen,
ce any matter contained in the alimentary canal, from
pper towards its lower extremity. The muscles of
alls of the ducts of the glands have a substantially
ar arrangement. In these cases the contraction of
fibre is less sudden and lasts longer than in the case
e heart.

uscles attached to definite levers.—The great
rity of the muscles in the body are attached to
ict levers, formed by the bones. In such bones as

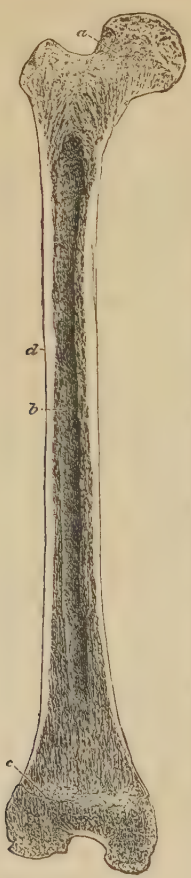


FIG. 91.—LONGITUDINAL SECTION OF THE SHAFT OF A HUMAN FEMUR OR THIGH-BONE.
a, the head, which articulates with the haunch-bone; *b*, the medullary cavity, and *d*, the dense bony substance of the shaft; *c*, the part which enters into the knee-joint, articulating with the shin-bone, or tibia.

are ordinarily employed as levers, the osseous tissue is arranged in the form of a **shaft** (Fig. 91 *d.*), formed of a

dense and compact osseous matter, but often contain-
great central cavity (*b*) which is filled with a very
re vascular and fibrous tissue loaded with fat called
row. Towards the two ends of the bone, the
act matter of the shaft thins out, and is replaced by
thicker but looser sponge-work of bony plates and
which is termed the **cancellous** tissue of the
The surface even of this part, however, is still
d by a thin sheet of denser bone.

least one end of each of these bony levers is fashioned
smooth, articular surface, covered with cartilage,
enables the relatively fixed end of the bone to play
the corresponding surface of some other bone with
it is said to be *articulated* (see p. 317), or, contrari-
allows that other bone to move upon it.

is one or other of these extremities which plays the
of fulcrum when the bone is in use as a lever.

us, in the accompanying figure (Fig. 92) of the bones
e upper extremity, with the attachments of the *biceps*
le to the shoulder-blade and to one of the two bones
e fore-arm called the *radius*, P indicates the point of
n of the power (the contracting muscle) upon the
s.

usually happens that the bone to which one end of a
le is attached is absolutely or relatively stationary ;
e that to which the other is fixed is movable. In
ase, the attachment to the stationary bone is termed
rigin, that to the movable bone the **insertion**, of
uscle.

e fibres of muscles are sometimes fixed directly into
arts which serve as their origins and insertions ; but,
commonly, strong cords or bands of fibrous tissue,
l **tendons**, are interposed between the muscle
r and its place of origin or insertion. When the
ns play over hard surfaces, it is usual for them to be
ated from these surfaces by sacs containing fluid,
n are called **bursæ** ; or even to be invested by

synovial sheaths, *i.e.* quite covered for some distance by a synovial bag forming a double sheath, very much in the same way that the bag of the pleura covers the lung and the chest-wall.

Usually, the direction of the axis of a muscle is that of a straight line joining its origin and its insertion. But in some muscles, as the *superior oblique muscle* of the eye, the tendon passes over a pulley formed by ligament, and

FIG. 92.—THE BONES OF THE UPPER EXTREMITY WITH THE BICEPS MUSCLE.

The two tendons by which this muscle is attached to the scapula are seen at *a*. P, indicates the attachment of the muscle to the radius, and hence the point of action of the power; F, the fulcrum, the lower end of the humerus on which the upper end of the radius (together with the ulna) moves; W, the weight (of the hand).

completely changes its direction before reaching its insertion. (See Lesson IX.)

Again, there are muscles which are fleshy at each end, and have a tendon in the middle. Such muscles are called *digastric*, or two-bellied. In the curious muscle which pulls down the lower jaw, and especially receives this name of *digastric*, the middle tendon runs through a pulley connected with the hyoid bone; and the muscle

h passes downwards and forwards from the skull to pulley, after traversing it, runs upwards and forwards e lower jaw (Fig. 93).

The General and Minute Structure of Bone.[1]—A long bone such as the femur and humerus of a , from which the attached muscles, tendons and ents have been carefully cleaned away, but the e of which has not been scraped or otherwise in-, is an excellent subject for the study of bone. It is rd tough body which is flexible and highly elastic n narrow limits, but readily breaks, with a clean

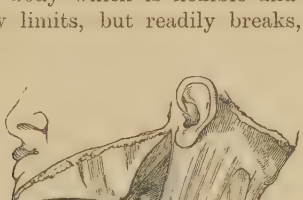


FIG. 93.—THE COURSE OF THE DIGASTRIC MUSCLE.

posterior belly ; D', its anterior belly ; between the two is the tendon passing through its pulley connected with *Hy*, the hyoid bone.

ure, if it is pressed too far. The two articular ends coated by a layer of cartilage which is thickest in the lle. Where the margins of the cartilage thin out a of vascular connective tissue commences, and ex-ing over the whole shaft, to the surface of which it is ly adherent, constitutes the **periosteum**. If the is macerated for some time in water, the periosteum be stripped off in shreds with the forceps. Filaments from its inner surface into the interior of the bone. he shaft is broken across it will be found to contain a

[1] The development of bone is described in Lesson XII.

spacious **medullary cavity** filled by a reddish, highly vascular mass of connective tissue, abounding in fat cells, called the **medulla** or **marrow**; and a longitudinal section shows that this medullary cavity extends through the shaft, but in the articular ends becomes subdivided by bony partitions and breaks up into smaller cavities, like the areolæ of connective tissue. These cavities are termed **cancelli**, and the ends of the bone are said to have a *cancellated* structure. The walls of the medullary cavity in the shaft are very dense, and exhibit no cancelli and appear at first to be solid throughout. But on examining them carefully with a magnifying glass it will be seen that they are traversed by a meshwork of narrow canals, varying in diameter from 20μ to 100μ or more. The long dimensions of the meshes lie parallel with the axis of the shaft. These are the **Haversian canals**. This system of Haversian canals opens by short communicating branches on the one hand upon the periosteal and on the other upon the medullary surface of the wall of the shaft; and in a fresh bone, minute vascular prolongations of the periosteum and of the medulla respectively, may be seen to pass into the communicating canals and become continuous with the likewise vascular contents of the Haversian canals. Moreover, at one part of the shaft there is a larger canal through which the vessels which supply the medulla pass. This is the so-called **nutritive foramen** of the bone. At the two ends of the bone the cavities of the Haversian canals open into those of the cancelli; and the vascular substance which fills the latter thus further connects the vascular contents of the Haversian canals with the medulla.

Thus the bone may be regarded as composed of (i) an internal, thick, cylinder of vascular medulla; (ii) an external, hollow, thin, cylindrical sheath of vascular periosteum, completed at each end by a plate of articular cartilage; (iii) of a fine, regular, long-meshed vascular network which connects the sides of the medullar

der with the periosteal sheath of the shaft ; (iv) of a
e. irregular vascular meshwork occupying at each end
pace between the medullary cylinder and the plate
rticular cartilage, and connected with the periosteum
e lateral parts of the articular end ; (v) of the hard,
t osseous tissue which fills the meshes of these two
orks. Such is the general structure of all long bones
cartilaginous ends, though some, as the ribs, possess
ide medullary cavity, but are simply cancellated in
nterior. In some very small bones even the cancelli
vanting. And there are many bones which have no
nection with cartilage at all.

a bone is exposed to a red heat for some time in a
d vessel nothing remains but a mass of white "bone-
," which has the general form of the bone, but is
brittle and easily reduced to powder. It consists
st entirely of calcium phosphate and carbonate. On
other hand, if the bone is digested in dilute hydro-
ric acid for some time the calcareous salts are dissolved
and a soft, flexible substance is left, which has the
t form of the bone, but is much lighter. If this is
d for a long time it will yield much gelatin, and only
nall residue will be left. Osseous tissue therefore
sists essentially of an animal matter impregnated with
ium salts, the animal matter being collagenous like
nective tissue.

sufficiently thin longitudinal section made by grinding
n part of the wall of the medullary cavity of a bone—
h has been well macerated in water and then
oughly dried—if viewed as a transparent object with
agnifying glass, shows a series of lines, with dark
rgements at intervals, running parallel with the
ersian canals. If the section, instead of being longi-
nal, were made transversely to the shaft, and there-
cutting through the majority of the Haversian canals
ight angles to their length, similar lines and dark
s would be seen to form concentric circles at regular

intervals round each Haversian canal (Fig. 94). The hard bony tissue appears therefore to be composed of **lamellæ**, which are disposed concentrically around the Haversian canals; and a Haversian canal with the concentric lamellæ belonging to it form what is called a **Haversian system**. The soft substance from which the bone-earth has been extracted is similarly lamellated, and here and there presents fibres which may be traced into the fibrous substance of the periosteum.

If a thin section of dry bone is examined with the microscope (Fig. 95), by transmitted light, each dark spot is seen to be a black body (of an average diameter of about 15μ) with an irregular jagged outline, and proceeding from it are numerous fine dark lines which ramify in the surrounding matrix and unite with similar branched lines from adjacent black bodies. The matrix itself has a somewhat granular aspect. In a transverse section these black bodies are rounded or oval in form, but in a longitudinal section they appear almost spindle-shaped; that is to say they are lenticular or lens-shaped, but flattened as it were between the adjacent layers of the matrix. Examined by reflected light the same bodies look white and glistening; and if the section instead of being examined dry, be boiled in water or soaked in strong alcohol, and brought under the microscope while still wet, the black bodies with their branching lines will be found to have almost disappeared, only faint outlines of them being left. At the same time minute bubbles of air will have escaped from the section. The black bodies seen in the dry bone are in fact "**lacunæ**," *i.e.* gaps, or holes in the solid matrix, appearing black by transmitted light and white by reflected light, because they are filled with air; and the dark branched lines are similarly, minute canals, "**canaliculi**," also filled with air-bubbles, drawn out so to speak into lines, also hollowed out of the solid matrix, and placing one lacuna in communication with another. In each Haversian

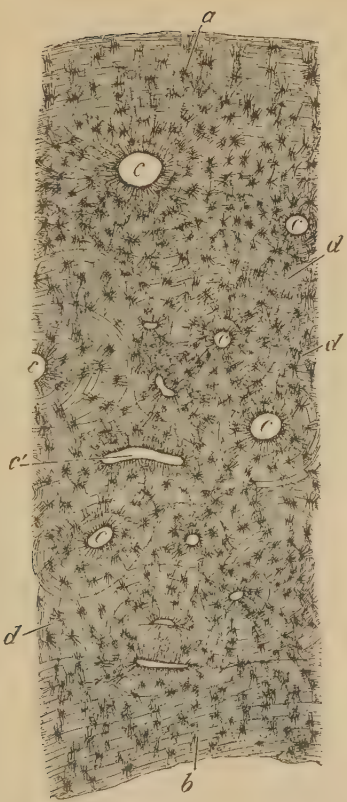


FIG. 94.—TRANSVERSE SECTION OF COMPACT BONE.

amellæ concentric with the external surface ; *b*, lamellæ concentric the medullary surface ; *c*, section of Haversian canals ; *c'*, section Haversian canal just dividing into two ; *d*, intersystemic lamellæ. magnifying power.

system the *canaliculi*, and the *lacunæ* of the innermost layer or that nearest the Haversian canal communicate with it, while the *canaliculi* and the *lacunæ* of the outermost layer communicate only with those of the next inner layer. Hence the *lacunæ* and *canaliculi* compose a

FIG. 95.—TRANSVERSE SECTION OF BONE, HIGHLY MAGNIFIED (300 DIAMETERS).

H, Haversian canals; *l*, lacunæ with canaliculi.

meshwork of canals, which is peculiar to each Haversian system, and by which the nutritive plasma exuded from the vessels in the canal of that system irrigates all the layers of bone which belong to the system.

A very thin section of perfectly fresh bone exhibits no dark bodies, inasmuch as the lacunæ and canaliculi con-

no air, but are permeated with the nutritive fluid. lacuna moreover, at all events in young bone, ins a nucleated cell, which is altogether similar in tial character to a connective tissue or cartilage scle, and if the term were not already misused be called a "**bone corpuscle**." In fact, in nate analysis the essential character of bone shows it- e be this: that it is a tissue analogous to cartilage and ective tissue in so far as it consists of cells separated uch intercellular substance; and that it differs from mainly in the fact that calcareous matter is deposited d associated with the intercellular substance in such y as to leave minute uncalcified passages (the *canali-*), which open into the larger uncalcified intervals (the *ne*), in the neighbourhood of the cells.

The function of these passages is doubtless to allow of ore thorough permeation of the calcified tissue by the itive fluids than could take place if the calcareous osit were continuous, and it is probable that, in an nary bone, there is no particle 1μ square which is not s brought within reach of a minute streamlet of itive plasma.

This circumstance enables us to understand that which would hardly suspect from the appearance of a bone, nely, that, throughout life, or, at all events, in early , its tissue is the seat of an extremely active vital cess. The permanence and apparent passivity of the ne are merely the algebraical summation of the contrary ocesses of destruction and reproduction which are ing on in it.

If a young pig is fed with madder, its bones will be und after a time to be dyed red. The madder dye, in ct, getting into the blood, permanently dyes the tissue ith which it meets in its course through the bones. But the pig is fed for a time with madder, and is en deprived of it, the amount of colour to be found in e bones depends on the time which elapses before the

pig is killed. And it is not that the colouring matter is merely, as it were, washed out; the dye is permanent, but the bones nevertheless become parti-coloured. In the shaft of a long bone, for instance, a certain time after feeding with madder, a deep red layer of bone in the middle of thickness of its wall will be found to have colourless bone on its medullary and on its periosteal face. And the longer the time which has elapsed since the feeding with madder, the more completely will the deep red bone be replaced and covered up by colourless bone.

10. The Mechanics of Motion. The System of Levers.—To understand the action of the bones, as levers, properly, it is necessary to possess a knowledge of the different kinds of levers and be able to refer the various combinations of the bones to their appropriate lever-classes.

A lever is a rigid bar, one part of which is absolutely or relatively fixed, while the rest is free to move. Some one point of the movable part of the lever is set in motion by a force, in order to communicate more or less of that motion to another point of the movable part, which presents a resistance to motion in the shape of a weight or other obstacle.

Three kinds of levers are enumerated by mechanicians, the definition of each kind depending upon the relative positions of the point of support, or **fulcrum**; of the point which bears the resistance, **weight**, or other obstacle to be overcome by the force; and of the point to which the force, or **power** employed to overcome the obstacle, is applied.

If the fulcrum be placed between the power and the weight, so that, when the power sets the lever in motion, the weight and the power describe arcs, the concavities of which are turned towards one another, the lever is said to be of the **first order**. (Fig. 96, I.)

If the fulcrum be at one end, and the weight be between

l the power, so that weight and power describe con-
ic arcs, the weight moving through the less space
the lever moves, the lever is said to be of the
ond order. (Fig. 96, II.)
d if, the fulcrum being still at one end, the power be
en the weight and it, so that, as in the former case,
power and weight describe concentric arcs, but

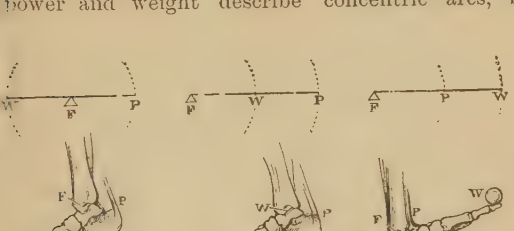


FIG. 96.

upper three figures represent the three kinds of levers; the lower, ot, when it takes the character of each kind. -W, weight or resist-; F, fulcrum; P, power.

power moves through the less space, the lever is of
third order. (Fig. 96, III.)
the human body the following parts present ex-
les of **levers of the first order.**
) The skull in its movements upon the atlas, as
rum.
) The pelvis in its movements upon the heads of the
h-bones, as *fulcrum.*
) The foot, when it is raised, and the toe tapped on
ground, the ankle-joint being *fulcrum.* (Fig. 96, I.)
he positions of the weight and of power are not
n in either of these cases, because they are reversed
rding to circumstances. Thus, when the face is being

depressed, the power is applied in front, and the weight to the back part, of the skull ; but when the face is being raised, the power is behind and the weight in front. The like is true of the pelvis, according as the body is bent forward, or backward, upon the legs. Finally, when the toes, in the action of tapping, strike the ground, the power is at the heel, and the resistance in the front of the foot. But when the toes are raised to repeat the act, the power is in front, and the weight, or resistance, is at the heel, being, in fact, the inertia and elasticity of the muscles and other parts of the back of the leg.

But in all these cases, the lever remains one of the first class, because the fulcrum, or fixed point on which the lever turns, remains between the power and the weight, or resistance.

The following are three examples of **levers of the second order** :—

(*a*) The thigh-bone of the leg which is bent up towards the body and not used, in the action of hopping.

For, in this case, the fulcrum is at the hip-joint. The power (which may be assumed to be furnished by the thick muscle[1] of the front of the thigh) acts upon the knee-cap ; and the position of the weight is represented by that of the centre of gravity of the thigh and leg, which will lie somewhere between the end of the knee and the hip.

(*b*) A rib when depressed by the *rectus* muscle[2] of the abdomen, in expiration.

Here the fulcrum lies where the rib is articulated with the spine ; the power is at the sternum virtually the opposite end of the rib ; and the resistance to be overcome lies between the two.

[1] This muscle, called *rectus*, is attached above to the haunch-bone and below to the knee-cap (Fig. 6, 2, p. 19). The latter bone is connected by a strong ligament with the *tibia*.

[2] This muscle lies in the front abdominal wall on each side of the middle line. It is attached to the sternum above and to the front of the pelvis below (Fig. 6, 3).

) The raising of the body upon the toes, in standing
iptoe, and in the first stage of making a step forwards.
. 96, II.)
lere the fulcrum is the ground on which the toes rest ;
power is applied by the muscles of the calf to the
(Fig. 6, I.) ; the resistance is so much of the weight
he body as is borne by the ankle-joint of the foot,
gh of course lies between the heel and the toes.
hree examples of **levers of the third order** are—
) The spine, head, and pelvis, considered as a rigid
which has to be kept erect upon the hip-joints.
. 6.)
lere the fulcrum lies in the hip-joints, the weight is
above the fulcrum, at the centre of gravity of the
d and trunk ; the power is supplied by the extensor
scles (Fig. 6, 2) in the front of, or the flexor muscles
. 6, II.) at the back of, the thigh, and acts upon points
paratively close to the fulcrum.
) Flexion of the forearm upon the arm by the **biceps**
scle, when a weight is held in the hand.
n this case, the weight being in the hand and the ful-
m at the elbow-joint, the power is applied at the point
ttachment of the tendon of the biceps, close to the
er. (Fig. 92.)
) Extension of the leg on the thigh at the knee-joint.
Here the fulcrum is the knee-joint ; the weight is at
centre of gravity of the leg and foot, somewhere be-
en the knee and the foot ; the power is applied by the
scles in front of the thigh (Fig. 6, 2 and Fig. 97),
ough the ligament of the knee-cap, or **patella**, to the
a, close to the knee-joint.
n studying the mechanism of the body, it is very im-
tant to recollect that one and the same part of the
y may represent each of the three kinds of levers,
ording to circumstances. Thus it has been seen that
foot may, under some circumstances, represent a lever
the first, in others, of the second, order. But it may

become a lever of the third order, as when one dances a weight resting upon the toes, up and down, by moving only the foot. In this case, the fulcrum is at the ankle-joint, the weight is at the toes, and the power is furnished by the extensor muscles at the front of the leg (Fig. 6, 1),

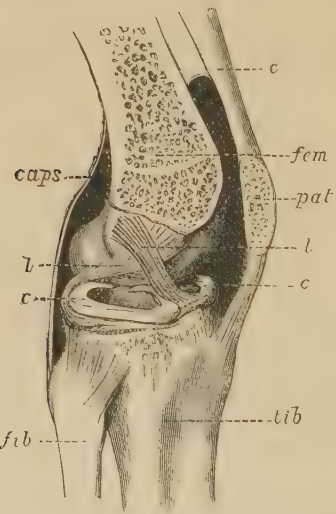


FIG. 97.—THE RIGHT KNEE-JOINT. THE OUTER HALF OF THE FEMUR AND PATELLA SAWN AWAY.

fem. femur; *pat.* patella; *tib.* tibia; *fib.* fibula; *caps.* capsule of joint; *l*, crucial ligaments; *c*, semilunar fibro-cartilages; *c*, tendon of extensor muscle.

which are inserted between the fulcrum and the weight. (Fig. 96, III.)

11. The Joints of the Body.—It is very important that the levers of the body should not slip, or work unevenly, when their movements are extensive, and to this end they

connected together in such a manner as to form strong
definitely-arranged **joints** or **articulations.**
oints may be classified into imperfect and perfect.
a) **Imperfect joints** are those in which the conjoined
rs (bones or cartilages) present no smooth surfaces,
ble of rotatory motion, to one another, but are con-
ted by continuous cartilages, or ligaments, and have
so much mobility as is permitted by the flexibility of
joining substance.
Examples of such joints as these are to be met with in
vertebral column—the flat surfaces of the bodies of
vertebræ being connected together by thick plates of
y flexible fibro-cartilage, which confer upon the whole
mn considerable play and springiness, and yet prevent
great amount of motion between the several vertebræ.
the pelvis (see Plate, Fig. VI. and Fig. 4), the pubic
nes are united to each other in front, and the iliac
nes to the sacrum behind, by fibrous or cartilaginous
ue, which allows of only a slight play, and so gives the
vis a little more elasticity than it would have if it were
one bone.
b) In all **perfect joints,** the opposed bony surfaces
ich move upon one another are covered with cartilage,
l between them is placed a sort of sac, which lines
se cartilages, and, to a certain extent, forms the side
lls of the joint ; and which, secreting a small quantity
viscid, lubricating fluid—the **synovia** is called a
novial membrane.
The opposed surfaces of these *articular* cartilages, as
y are called, may be spheroidal, cylindrical, or pulley-
ped ; and the convexities of the one answer, more or
s completely, to the concavities of the other.
Sometimes, the two articular cartilages do not come
ectly into contact, but are separated by independent
tes of cartilage, which are termed *inter-articular.* The
posite faces of these inter-articular cartilages are fitted
receive the faces of the proper articular cartilages.

While these co-adapted surfaces and synovial membranes provide for the free mobility of the bones entering into a joint, the nature and extent of their motion is defined, partly by the forms of the articular surfaces, and partly by the disposition of the **ligaments**, or firm, fibrous cords which pass from one bone to the other.

As respects the nature of the articular surfaces, joints may be what are called **ball and socket joints**, when the spheroidal surface furnished by one bone plays in a cup furnished by another. In this case the motion of the former bone may take place in any direction, but the extent of the motion depends upon the shape of the cup —being very great when the cup is shallow, and small in proportion as it is deep. The shoulder is an example of a ball and socket joint with a shallow cup (Fig. 5, B); the hip, of such a joint with a deep cup (Fig. 98).

Hinge-joints are single or double. In the former case, the nearly cylindrical head of one bone fits into a corresponding socket of the other. In this form of hinge-joint the only motion possible is in the direction of a plane perpendicular to the axis of the cylinder, just as a door can only be made to move round an axis passing through its hinges. The elbow is the best example of this joint in the human body, but the movement here is limited, because the **olecranon**, or part of the ulna which rises up behind the humerus, prevents the arm being carried back behind the straight line; the arm can thus be bent to, or straightened, but not bent back (Fig. 99). The knee (Fig. 97) and ankle present less perfect specimens of a single hinge-joint.

A double hinge-joint is one in which the articular surface of each bone is concave in one direction, and convex in another, at right angles to the former. A man seated in a saddle is "articulated" with the saddle by such a joint. For the saddle is concave from before backwards, and convex from side to side, while the man presents to it

concavity of his legs astride, from side to side, and convexity of his seat, from before backwards.

The metacarpal bone of the thumb is articulated with

98.—A Section of the Hip-joint taken through the Acetabulum or Articular Cup of the Pelvis and the middle of the head and neck of the Thigh-bone.

T, Ligamentum teres, or round ligament. The spaces marked with interrupted line (- - - -) represent the articular cartilages. The cavity the synovial membrane is indicated by the dark line between these, as is shown, extends along the neck of the femur beyond the limits the cartilage. The peculiar shape of the pelvis causes the section to the remarkable outline shown in the cut. This will be intelligible mpared with Fig. VI. in the plate.

bone of the wrist, called *trapezium*, by a double hinge-

t.

A **pivot-joint** is one in which one bone furnishes an , or pivot, on which another turns ; or itself turns on

its own axis, resting on another bone. A remarkable example of the former arrangement is afforded by the **atlas** and **axis**, or two uppermost vertebræ of the neck (Fig. 100). The axis possesses a vertical peg, the so-called **odontoid** process (*b*), and at the base of the peg are two,

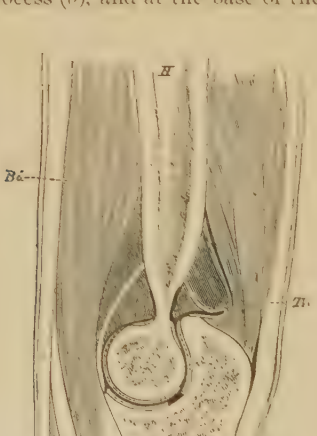


FIG. 99. LONGITUDINAL AND VERTICAL SECTION THROUGH THE ELBOW-JOINT.

H, humerus; *UL*, ulna; *Tr*, the *triceps* muscle, which extends the arm; *Bi*, the *biceps* muscle, which flexes it.

obliquely placed, articular surfaces (*a*). The atlas is a ring-like bone, with a massive thickening on each side. The inner side of the front of the ring plays round the neck of the odontoid peg, and the under surfaces of the lateral masses glide over the articular faces on each side of the base of the peg. A strong ligament passes between

ner sides of the two lateral masses of the atlas, and
the hinder side of the neck of the odontoid peg
place (Fig. 100, A). By this arrangement, the atlas
abled to rotate through a considerable angle either
upon the axis, without any danger of falling forwards
ckwards—accidents which would immediately destroy
y crushing the spinal cord.
e lateral masses of the atlas have, on their upper
, concavities (Fig. 100, A, *a*) into which the two con-
occipital condyles of the skull fit, and in which they

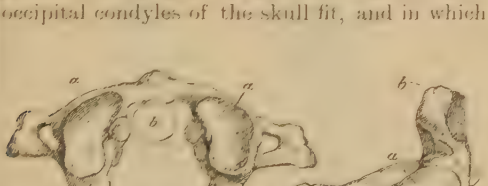


FIG. 100.

The atlas viewed from above; *a a* upper articular surfaces of its
al masses for the condyles of the skull; *b*, the peg of the axis
bra.
Side view of the axis vertebra; *a*, articular surface for the lateral
of the atlas; *b*, peg or odontoid process.

upward and downward. Thus the nodding of the
is effected by the movement of the skull upon the
; while, in turning the head from side to side, the
does not move upon the atlas, but the atlas slides
d the odontoid peg of the axis vertebra.
e second kind of pivot-joint is seen in the forearm.
the elbow and forearm, as far as the wrist, are made
st upon a table, and the elbow is kept firmly fixed,
hand can nevertheless be freely rotated so that either
palm, or the back, is turned directly upwards. When
palm is turned upwards, the attitude is called

supination (Fig. 101, A); when the back, **pronation** (Fig. 101, B).

The forearm is composed of two bones: one, the **ulna**, which articulates with the **humerus** at the elbow by the hinge-joint already described, in such a manner that it can

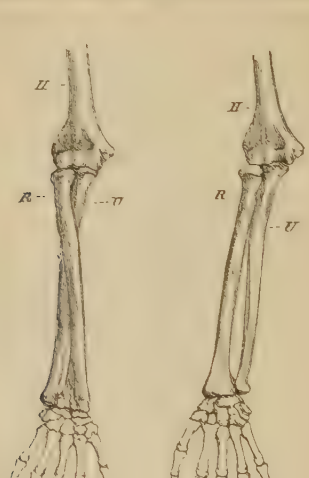


FIG. 101.

The bones of the right forearm in supination (A) and pronation (B). *H*, humerus; *R*, radius; *U*, ulna.

move only in flexion and extension (see p. 318), and has no power of rotation. Hence, when the elbow and wrist are rested on a table, this bone remains unmoved.

But the other bone of the forearm, the **radius**, has its small upper end shaped like a very shallow cup with thick

e. The hollow of the cup articulates with a spheroidal ce furnished by the humerus: the lip of the cup, a concave depression on the side of the ulna.

e large lower end of the radius bears the hand, and n the side next the ulna, a concave surface, which ulates with the convex side of the small lower end of bone.

us the upper end of the radius turns on the double ce, furnished to it by the pivot-like ball of the humer- nd the partial cup of the ulna; while the lower end e radius can rotate round the surface furnished to it he lower end of the ulna.

supination, the radius lies parallel with the ulna, its lower end to the outer side of the ulna (Fig. 101, In *pronation*, it is made to turn on its own axis e, and round the ulna below, until its lower half es the ulna, and its lower end lies on the inner side e ulna (Fig. 101, B).

he ligaments which keep the mobile surfaces of bones ther are, in the case of ball and socket joints, strong us *capsules* which surround the joint on all sides. In e-joints, on the other hand, the ligamentous tissue is ly accumulated, in the form of **lateral ligaments**, he sides of the joints. In some cases ligaments are ed within the joints, as in the knee, where the bundles ores which cross obliquely between the femur and the are called **crucial** ligaments (Fig. 97, *l*); or, as he hip, where the **round ligament** passes from the om of the socket, or acetabulum of the pelvis to ball furnished by the head of the femur (Fig. 98).

gain, two ligaments pass from the apex of the odontoid to both sides of the margin of the occipital foramen, he large hole in the base of the skull, through which spinal cord passes to join the brain; these, from their tion in helping to stop excessive rotation of the skull, called **check ligaments** (Fig. 102, *a*).

one joint of the body, the hip, the socket or **aceta-**

bulum (Fig. 98) fits so closely to the head of the femur and the capsular ligament so completely closes its cavity on all sides, that the pressure of the air must be reckoned among the causes which prevent dislocation. This has been proved experimentally by boring a hole through the floor of the acetabulum, so as to admit air into its cavity, when the thigh-bone at once falls as far as the round and capsular ligaments will permit it to do, showing that it was previously pushed close up by the pressure of the external air.

12. **The Various Movements of the Body.** The different kinds of movement which the levers thus connected are capable of performing are called **flexion** and **extension**; **abduction** and **adduction**; **rotation** and **circumduction**.

A limb is *flexed*, when it is bent: *extended*, when it is straightened out. It is *abducted*, when it is drawn away from the middle line: *adducted*, when it is brought to the middle line. It is *rotated*, when it is made to turn on its own axis: *circumducted*, when it is made to describe a conical surface by rotation round an imaginary axis.

No part of the body is capable of perfect rotation like a wheel, for the simple reason that such motion would necessarily tear all the vessels, nerves, muscles, &c., which unite it with other parts.

Any two bones united by a joint may be moved on upon another in, at fewest, two different directions. In the case of a pure hinge-joint, these directions must be opposite and in the same plane: but, in all other joints the movements may be in several directions and in various planes.

In the case of a pure hinge-joint, the two practicable movements—viz., flexion and extension—may be effected by means of two muscles, one for each movement, and running from one bone to the other, but on opposite sides of the joint. When either of these muscles contracts, it will pull its attached ends together, and bend or straighten

ase may be, the joint towards the side on which aced. Thus the biceps muscle is attached, at i, to the shoulder-blade, while, at the other end, on passes in front of the elbow-joint to the radius 2 and 99, *Bi*) : when this muscle contracts, there- bends, or flexes, the forearm on the arm. At the he joint there is the triceps (*Tr*, Fig. 99) : when

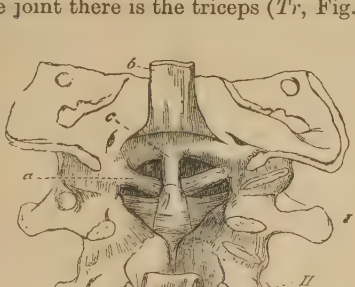


Fig. 102.

rtebral column in the upper part of the neck laid open to show, eck ligaments of the axis ; *b*, the broad ligament which extends front margin of the occipital foramen along the hinder faces of es of the vertebræ ; it is cut through, and the cut ends turned show, *c*, the special ligament which connects the point of the id " peg with the front margin of the occipital foramen ; *I*, the *I*, the axis.

ntracts, it straightens, or extends, the forearm on m.

he other extreme form of articulation—the ball and joint—movement in any number of planes may be d, by attaching muscles in corresponding number rection, on the one hand, to the bone which affords cket, and on the other to that which furnishes the Circumduction will be effected by the combined uccessive contraction of these muscles.

13. The Mechanics of Locomotion.—We may now pass from the consideration of the mechanism of mere motion to that of locomotion.

When a man who is standing erect on both feet proceeds to *walk*, beginning with the right leg, the body is inclined, so as to throw the centre of gravity forward; and, the right foot being raised, the right leg is advanced for the length of a step, and the foot is put down again. In the meanwhile, the left heel is raised, but the toes of the left foot have not left the ground when the right foot has reached it, so that there is no moment at which both feet are off the ground. For an instant, the legs form two sides of an equilateral triangle, and the centre of the body is consequently lower than it was when the legs were parallel and close together.

The left foot, however, has not been merely dragged away from its first position, but the muscles of the calf, having come into play, act upon the foot as a lever of the second order, and thrust the body, the weight of which rests largely on the left astragalus, upwards, forwards, and to the right side. The momentum thus communicated to the body causes it, with the whole right leg, to describe an arc over the right astragalus, on which that leg rests below. The centre of the body consequently rises to its former height as the right leg becomes vertical, and descends again as the right leg, in its turn, inclines forward.

When the left foot has left the ground, the body is supported on the right leg, and is well in advance of the left foot; so that, without any further muscular exertion, the left foot swings forward like a pendulum, and is carried by its own momentum beyond the right foot, to the position in which it completes the second step.

When the intervals of the steps are so timed that each swinging leg comes forward into position for a new step without any exertion on the part of the walker, walking is effected with the greatest possible economy of force.

as the swinging leg is a true pendulum—the time of tion of which depends, other things being alike, its length (short pendulums vibrating more quickly long ones),—it follows that, on the average, the al step of short-legged people is quicker than that ng-legged ones.

running, there is a period when both legs are off the nd. The legs are advanced by muscular contraction, the lever action of each foot is swift and violent. ed, the action of each leg resembles, in violent ing, that which, when both legs act together, consti- s a *jump*, the sudden extension of the legs adding e impetus, which, in slow walking, is given only by feet.

. **The Mechanism of the Larynx.**—Perhaps the singular motor apparatus in the body is the *larynx*, he agency of which *voice* is produced.

ne essential conditions of the production of the human e are :—

) The existence of the so-called *vocal cords*.

) The parallelism of the edges of these cords, without h they will not vibrate in such a manner as to give sound.

A certain degree of tightness of the vocal cords, out which they will not vibrate quickly enough to uce sound.

) The passage of a current of air between the parallel s of the vocal cords of sufficient power to set the s vibrating.

e larynx is a short tubular box opening above into bottom of the pharynx and below into the top of rachea. Its framework is supplied by certain carti- more or less movable on each other, and these are ected together by joints, membranes, and muscles. ss the middle of the larynx is a transverse partition, ed by two folds of the lining mucous membrane, ching from either side, but not quite meeting in the

middle line. They thus leave, in the middle line, a chink or slit, running from the front to the back, called the **glottis**. The two edges of this slit are not round and flabby, but sharp and, so to speak, clean cut; they are also strengthened by a quantity of elastic tissue, the fibres of which are disposed lengthways in them. These sharp free edges of the *glottis* are the so-called **vocal cords**, or *vocal ligaments*.

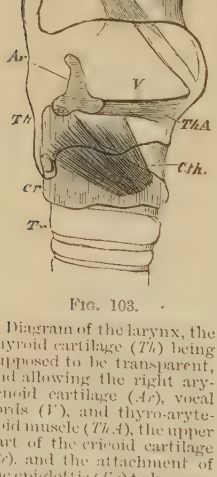


FIG. 103.

Diagram of the larynx, the thyroid cartilage (*Th*) being supposed to be transparent, and allowing the right arytenoid cartilage (*Ar*), vocal cords (*V*), and thyro-arytenoid muscle (*Th A*), the upper part of the cricoid cartilage (*Cr*), and the attachment of the epiglottis (*Ep*) to be seen. *C.th*, the right crico-thyroid muscle; *Tr*, the trachea; *Hy*, the hyoid bone.

The **thyroid** cartilage (Fig. 103, *Th*) is a broad plate of gristle bent upon itself into a V shape, and so disposed that the point of the V is turned forwards, and constitutes what is commonly called "Adam's apple." Above, the thyroid cartilage is attached by ligament and membrane to the **hyoid** bone (Fig. 103, *Hy*). Below and behind, its broad sides are produced into little elongations or horns, which are articulated by ligaments with the outside of a great ring of cartilage, the **cricoid** (Fig. 103, *Cr*), which forms, as it were, the top of the windpipe.

The *cricoid* ring is much higher behind than in front, and a gap, filled up by membrane only, is left between its upper edge and the lower edge of the front part of the thyroid, when the latter is horizontal. Consequently, the thyroid cartilage, turning upon the articulations of its horns with the hinder part of the cricoid, as upon hinges, can be moved up and down through the space occupied by

membrane ; or, if the thyroid cartilage is fixed, the id cartilage moves in the same way upon its articula- with the thyroid. When the thyroid moves down- ls or the cricoid upwards, distance between the front of the thyroid cartilage the back of the cricoid is ssarily increased ; and when reverse movement takes e the distance is diminished. re is, on each side, a large cle, the **crico-thyroid**, ch passes from the outer of the cricoid cartilage iquely upwards and back- ds to the thyroid, and pulls latter down ; or, if the roid is fixed, pulls the cricoid (Fig. 103, *C.th*). erched side by side upon upper edge of the back part he cricoid cartilage are two all irregularly-shaped but, ghly speaking, pyramidal tilages, the **arytenoid** car- ges (Fig. 105, *Ary*). Each these is articulated by its e with the cricoid cartilage means of a shallow joint ich permits of very varied vements, and especially al- s the front portions of the two arytenoid cartilages to proach, or to recede from, each other.

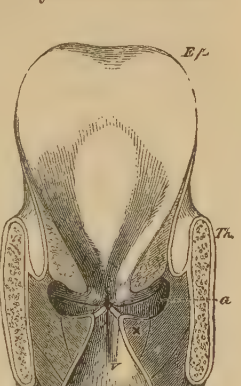


FIG. 104.—VERTICAL AND TRANSVERSE SECTION THROUGH THE LARYNX, THE HINDER HALF OF WHICH IS REMOVED.

Ep. Epiglottis ; *Th.* thyroid cartilage ; *a*, cavities called the *ventricles of larynx* above the vocal ligaments (*V*); × the right thyro-arytenoid muscle cut across ; *Cr.* the cricoid cartilage.

t is to the forepart of one of these arytenoid cartilages t the hinder end of each of the two vocal ligaments is tened ; and they stretch from these points horizontally oss the cavity of the larynx, to be attached, close to-

gether, in the re-entering angle of the thyroid cartilage rather lower than half-way between its top and bottom.

Now when the arytenoid cartilages diverge, as they do when the larynx is in a state of rest, it is evident that the aperture of the glottis will be V-shaped, the point of the V being forwards, and the base behind.

For, in front, or in the angle of the thyroid, the two

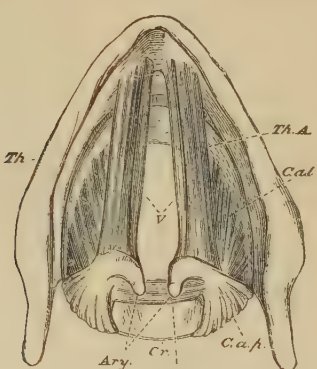


FIG. 105.—THE PARTS SURROUNDING THE GLOTTIS PARTIALLY DISSECTED AND VIEWED FROM ABOVE.

Th. the thyroid cartilage; *Cr.* the cricoid cartilage; *V*, the edges of the vocal ligaments bounding the glottis; *Ary*, the arytenoid cartilages; *Th.A*, thyro-arytenoid; *C.a.l.* lateral crico-arytenoid; *C.a.p*, posterior crico-arytenoid; *Ar.p*, posterior arytenoid muscles.

vocal ligaments are fastened permanently close together, whereas, behind, their extremities will be separated as far as the arytenoids, to which they are attached, are separated from each other. Under these circumstances a current of air passing through the glottis produces no sound, the parallelism of the vocal cords being wanting; whence it is that, ordinarily, expiration and inspiration take place quietly. Passing from one arytenoid cartilage to the

r, at their posterior surfaces are certain muscles
l the **posterior arytenoid** (Fig. 105, *Ar.p.*).
e are also two sets of muscles connecting each
noid with the cricoid, and called from their positions
ctively the **posterior** and **lateral crico-ary-**
oid (Fig. 105, *C.a.p. C.a.l.*). By the more or less
ate or combined action of these muscles, the
noid cartilages, and especially the front part of these
lages and, consequently, the hinder ends of the vocal
s attached to them, may be made to approach or
de from each other, and thus the vocal cords rendered
llel or the reverse.

e have seen that the crico-thyroid muscle pulls the
oid cartilage down, or the cricoid cartilage up, and
increases the distance between the front of the
oid and the back of the cricoid, on which the
enoids are seated. This movement, the arytenoids
g fixed, must tend to pull out the vocal cords
thways, or in other words to tighten them.

unning from the re-entering angle in the front part
ie thyroid, backward, to the arytenoids, alongside the
l cords (and indeed imbedded in the transverse folds,
which the cords are the free edges) are two strong
cles, one on each side (Fig. 105, *Th.A.*), called
ro-arytenoid. The effect of the contraction of
e muscles is to pull up the thyroid cartilage after it
been depressed by the crico-thyroid muscles, (or to
down the cricoid after it has been raised,) and conse-
ntly to slacken the vocal cords.

hus the parallelism (*b*) of the vocal cords is deter-
ed chiefly by the relative distance from each other of
arytenoid cartilages ; the tension (*c*) of the vocal cords
etermined chiefly by the upward or downward move-
t of the thyroid or cricoid cartilage ; and both these
litions are dependent on the action of certain muscles.
he current of air (*d*) whose passage sets the cords
ating is supplied by the movements of expiration,

which, when the cords are sufficiently parallel and tense, produce that musical note which constitutes the voice, but otherwise give rise to no audible sound at all.

15. The Voice.—Voice consists simply of the sound, or musical note, which results from the vibration of the

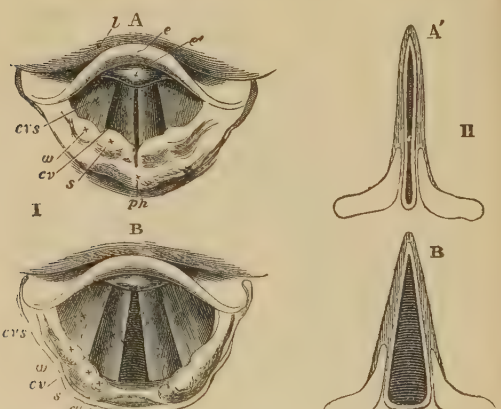


FIG. 106.

I. View of the human larynx from above as actually seen by the aid of the instrument called the laryngoscope; A, in the condition when voice is being produced; B, at rest when no voice is produced.

e. Epiglottis (foreshortened).

c.v. The vocal cords.

c.v.s. The so-called false vocal cords, folds of mucous membrane lying above the real vocal cords.

a. Elevation caused by the arytenoid cartilages.

s.v. Elevations caused by small cartilages connected with the arytenoids.

l. Root of the tongue.

II. Diagram of the same.

vocal cords. Other things being alike, the musical note will be low or high, according as the vocal cords are relaxed or tightened: and this again depends upon the relative predominance of the contraction of the crico

5d and thyro-arytenoid muscles. For when the -arytenoid muscles are fully contracted, the thyroid ıge will be raised, relatively to the cricoid, as far as go, and the vocal cords will be rendered relatively while, when the crico-thyroid muscles are fully ıcted, the thyroid cartilage will be depressed, ively to the cricoid, as much as possible, and the cords will be made more tense.

while a low note is being sounded, the tip of the : be placed on the crico-thyroid space (which can it, through the skin, beneath the lower edge of the id cartilage), and a high note be then suddenly pro- l, the crico-thyroid space will be found to be narrowed ıe approximation of the front edges of the cricoid and id cartilages. At the same time, however, the whole ıx is, to a slight extent, moved bodily upwards and wn forwards, and the cricoid has a particularly dis- upward movement; this movement of the whole ıx must be carefully distinguished from the motion ıe thyroid relatively to the cricoid.

ıe **range** of any voice depends upon the difference of ion which can be given to the vocal cords, in these positions of the thyroid cartilage. **Accuracy** of ing depends upon the precision with which the singer voluntarily adjust the contractions of the thyro- enoid and crico-thyroid muscles—so as to give his l cords the exact tension at which their vibration yield the notes required.

he **quality** of a voice—treble, bass, tenor, &c.—on other hand, depends upon the make of the particular nx, the primitive length of its vocal cords, their icity, the amount of resonance of the surrounding s, and so on.

hus, men have deeper notes than boys and women, use their larynxes are larger and their vocal cords er—whence, though equally elastic, they vibrate less tly.

16. Speech.—Speech is voice modulated by the throat, tongue, and lips. Thus, voice may exist without speech; and it is commonly said that speech may exist without voice, as in whispering. This is only true, however, if the title of voice be restricted to the sound produced by the vibration of the vocal cords; for, in whispering, there is a sort of voice produced by the vibration of the muscular walls of the lips which thus replace the vocal cords. A whisper is, in fact, a very low whistle.

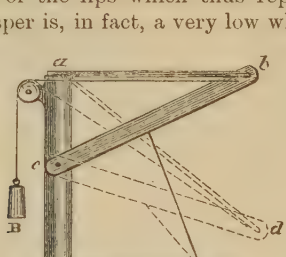


FIG. 107.

Diagram of a model illustrating the action of the levers and muscles of the larynx. The stand and vertical pillar represent the cricoid and arytenoid cartilages, while the rod (*b c*), moving on a pivot at *c*, takes the place of the thyroid cartilage; *a b* is an elastic band representing the vocal ligament. Parallel with this runs a cord fastened at one end to the rod *b c*, and, at the other, passing over a pulley to the weight B. This represents the thyro-arytenoid muscle. A cord attached to the middle of *b c*, and passing over a second pulley to the weight A, represents the crico-thyroid muscle. It is obvious that when the bar (*b c*) is pulled down to the position *c d*, the elastic band (*a b*) is put on the stretch.

The *modulation* of the voice into speech is effected by changing the form of the cavity of the mouth and nose, by the action of the muscles which move the walls of those parts.

Thus, if the pure **vowel** sounds—

E (as in *he*), *A* (as in *hay*), *A′* (as in *ah*),
O (as in *or*), *O′* (as in *oh*), *OO* (as in *cool*),

are pronounced successively, it will be found that they

be all formed out of the sound produced by a con-
us expiration, the mouth being kept open, but the
of its aperture, and the extent to which the lips are
t out or drawn in so as to lengthen or shorten the
nce of the orifice from the larynx, being changed for
vowel. It will be narrowest, with the lips most
n back, in *E*, widest in *A'*, and roundest, with the
most protruded, in *OO*.

rtain **consonants** also may be pronounced without
upting the current of expired air, by modification of
orm of the throat and mouth.

us the **aspirate**, H, is the result of a little extra
ratory force—a sort of incipient cough. *S* and *Z*, *Sh*
J (as in *jugular* = *G* soft, as in *gentry*), *Th*, *L*, *R*, *F*,
may likewise all be produced by continuous currents of
orced through the mouth, the shape of the cavity of
h is peculiarly modified by the tongue and lips.

ll the vocal sounds hitherto noted so far resemble one
her, that their production does not involve the
page of the current of air which traverses either of the
ulating passages.

ut the sounds of *M* and *N* can only be formed by
king the current of air which passes through the
th, while free passage is left through the nose. For
he mouth is shut by the lips ; for *N*, by the application
e tongue to the palate.

he other consonantal sounds of the English language
produced by shutting the passage through both nose
mouth ; and, as it were, forcing the expiratory vocal
ent through the obstacle furnished by the latter, the
acter of which obstacle gives each consonant its
liarity. Thus, in producing the consonants *B* and *P*,
nouth is shut by the lips, which are then forced open
is **explosive** manner. In *T* and *D*, the mouth pas-
is suddenly barred by the application of the point of
ongue to the teeth, or to the front part of the palate ;
e in *K* and *G* (hard, as in *go*) the middle and back of

the tongue are similarly forced against the back part of the palate.

An artificial larynx may be constructed by properly adjusting elastic bands, which take the place of the vocal cords; and, when a current of air is forced through these, due regulation of the tension of the bands will give rise to all the notes of the human voice. As each vowel and consonantal sound is produced by the modification of the length and form of the cavities, which lie over the natural larynx, so, by placing over the artificial larynx chambers to which any requisite shape can be given, the various letters may be sounded. It is by attending to these facts and principles that various speaking machines have been constructed.

Although the tongue is credited with the responsibility of speech, as the "unruly member," and undoubtedly takes a very important share in its production, it is not absolutely indispensable. Hence, the apparently fabulous stories of people who have been enabled to speak, after their tongues had been cut out by the cruelty of a tyrant, or persecutor, may be quite true.

Some years ago I had the opportunity of examining a person, whom I will call Mr. R., whose tongue had been removed as completely as a skilful surgeon could perform the operation. When the mouth was widely opened, the truncated face of the stump of the tongue, apparently covered with new mucous membrane, was to be seen, occupying a position as far back as the level of the anterior pillars of the fauces. The dorsum of the tongue was visible with difficulty; but I believe I could discern some of the circumvallate papillæ upon it. None of these were visible upon the amputated part of the tongue, which had been preserved in spirit; and which, so far as I could judge, was about $2\frac{1}{2}$ inches long.

When his mouth was open, Mr. R. could advance his tongue no further than the position in which I saw it; but he informed me that, when his mouth was shut,

ump of the tongue could be brought much more rd.

R.'s conversation was perfectly intelligible; and words as *think*, *the*, *cow*, *kill*, were well and clearly nced. But tin became *fin;* tack, *fack* or *pack;* ool; dog, *thog;* dine, *vine;* dew, *thew;* cat, *catf;* *adf;* goose, *gooth;* big, pig, *bich*, *pich*, with a al *ch*.

act, only the pronunciation of those letters the formation of which requires the use of the tongue was affected; of these, only the two which involve the employment tip were absolutely beyond Mr. R.'s power. He rted all *t's*, and *d's* into *f's*, *p's*, *v's*, or *th's*. *Th* was given in all cases; *s* and *sh*, *l* and *r*, with more or a lisp. Initial *g's* and *k's* were good; but final *g's* all more or less guttural. In the former case, the fect stoppage of the current of air by the root of the e was of no moment, as the sound ran on into that e following vowel; while, when the letter was ter-, the defect at once became apparent.

LESSON VIII

SENSATIONS AND SENSORY ORGANS

1. Movement the Result of Reflex Action.—The agent by which all the motor organs (except the cilia) described in the preceding Lesson are set at work, is muscular fibre. But, in the living body, muscular fibre is, as a rule, made to contract by a change which takes place in the **motor** or **efferent nerve**, which is distributed to it. This change again is generally effected by the activity of the **central nervous** system, with which the motor nerve is connected. The central organ is thrown into activity, directly or indirectly, by the influence of changes which take place in nerves, called **sensory** or **afferent**, which are connected, on the one hand, with the central organ, and, on the other hand, with some other part, usually on the surface, of the body. Finally, the alteration of the afferent nerve is itself produced by changes in the condition of the part of the body with which it is connected; which changes usually result from external impressions brought to bear on that part.

Sometimes the central organ enters into a state of activity without our being able to trace that activity to any direct influence of changes in afferent nerves; the activity seems to take origin in the central organ, and the movements to which it gives rise are called "spontaneous," or "voluntary." Putting these cases on one side it may be stated that a movement of the body, or of a part of it, is to be regarded as the effect of an influence

cally termed a **stimulus**) applied directly, or in-
y, to the ends of *afferent nerves*, and giving rise to a
ation of the condition of the particles or *molecules*
form the substance of the nerve fibres, *i.e.*, to a
cular change, which is propagated from molecule
ecule along the fibres to the *central nervous system*
hich these are connected. The molecular activity
afferent nerve sets up changes of a like order in the
and cells of the central organ ; from these the dis-
ace is transmitted along the *motor nerves*, which pass
he central organ to certain muscles. And, when
sturbance in the molecular condition of the efferent
s reaches the endings of those nerves in muscular
, a similar disturbance is communicated to the sub-
e of the muscular fibres, whereby, in addition to the
ction of certain other phenomena to some of which
nce has already been made (Lesson VII.), the parti-
f the muscular substance are made to take up a new
on, so that each fibre shortens and becomes thicker,
movement ensues. Thus, for instance, if we *un-
tionally* prick one of our fingers or touch some very
bject the hand is jerked away almost before we are
e of what has happened.

ch a series of molecular changes as that just described
led a **reflex action** : the disturbance in the afferent
es caused by the irritation being as it were *reflected*
along the efferent nerves, to the muscles. But the
e is not a good one, since it seems to imply that the
cular changes in the afferent nerve, the central organ,
the efferent nerve are all alike, and differ only in
tion ; whereas there is reason to think that they differ
ny ways.

e several structures necessary for the carrying out of
scular contraction, resulting in movement, in the
ve have described may be made clear by the following
am.

e stimulus is applied to a sensory surface (*S*) ; the

change thus set up is propagated as a molecular disturb ance (or impulse) along the sensory (afferent) nerve, *a.f* to *c*, a part of the central nervous system (the spina cord). The changes which then take place in *c* result i the setting up of a molecular disturbance in the moto (efferent nerve), *e.f.*, which is conveyed outwards alon that nerve to the muscle M^1, usually on the same side o the body. Sometimes the impulse is sent out along motor nerve to some muscle M^2 on the opposite side o the body.

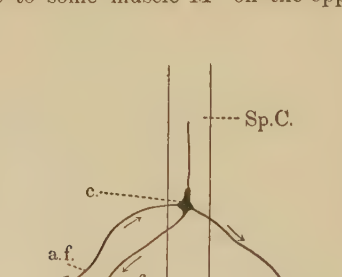


FIG. 108.—DIAGRAM TO ILLUSTRATE THE PATHS OF REFLEX ACTION.

Sp.c, spinal cord. *S*, some sensory surface; *a.f*, afferent or senso nerve; *c*, central connection in nervous system; *e.f*, *e.f*, efferent or mot fibres; M^1, M^2, muscles. The arrows show the directions in which t impulses travel.

2. **Sensations and Consciousness.**—A reflex actio may take place without our knowing anything about i and hundreds of such actions are continually going on our bodies without our being aware of them. But it ve frequently happens that we learn that something is goi on, when a stimulus affects our afferent nerves, by havi what we call a *feeling* or **sensation.** We class sens tions along with **emotions** and **volitions,** a

ghts, under the common head of **states of** ciousness. But what consciousness is we know and how it is that anything so remarkable as a state sciousness comes about as the result of irritating is tissue, is just as unaccountable as any other ulti- fact of nature.

sations are of very various degrees of definiteness. arise within ourselves, we know not how or where, main vague and undefinable. Such are the sensa- of *uncomfortableness*, of *faintness*, of *fatigue*, or of *ness*. We cannot assign any particular place to sensations, which are very probably the result of ions of the afferent nerves in general brought about e state of the blood, or that of the tissues in which are distributed. And however real these sensations be, and however largely they enter into the sum r pleasures and pains, they tell us absolutely nothing e external world. They are not only *diffuse*, but they lso **subjective** sensations.

The Special Senses.—In the case of other sen- s, each feeling arises out of changes taking place in nite part of the body, is produced by a stimulus ed to that part of the body, and cannot be produced imuli applied to other parts of the body. Thus the tions of **taste** and **smell** are confined to certain ns of the mucous membrane of the mouth and nasal es ; those of **sight** and **hearing** to the particular of the body called the eye and the ear ; and those of **ch**, though arising over a much wider area than thers, are nevertheless restricted to the skin and to portions of the membranes lining the internal cavities e body. Any portion of the body to which a sen- n is thus restricted is called a **sense-organ.**

may be here remarked that in the case of the sensa- f touch, the simple feeling of contact is accompanied formation, not only as to what sense-organ, but also what part of that sense-organ, is being affected.

When we touch a hot or a rough body with the tip of a finger, we are aware not only that we are dealing with a hot or a rough body, but also that the hot or rough body is in contact with the tip of the finger; we "refer," as is said, the sensation to that part of the tip of the finger which is being acted upon by the body in question. With the other sensations the case is different. When we smell a bad smell, though we know that we smell by the nose, we do not consider that the smell arises in the nose; we conclude that there is some object outside ourselves which is causing the bad smell. We refer the origin of the sensation to some external cause, and that even when the sensation is after all due to changes taking place in the nose itself independently of external objects, as in the unpleasant odours which accompany certain diseases of the nose. Similarly all our sensations of sight and of hearing are referred to external objects; and even in the case of taste, when a lump of sugar is taken into the mouth, we are simply aware of a sensation of sweetness and do not associate that sensation of sweetness with any particular part of the mouth, though, by the sense of touch, which the inside of the mouth also possesses, we can tell pretty exactly whereabouts in the mouth the melting lump is lying.

4. The General Plan of a Sense-organ. --In these sensations, thus arising in special sense-organs, and hence often spoken of as "special" sensations, each sensation or feeling results from the application of a particular kind of stimulus to its appropriate sense-organ; and, in each case, the structure of the sense-organ is arranged in such a manner as to render that organ peculiarly sensitive to its appropriate stimulus.

Thus the sensations of sight are brought about by the action of the vibrations of the luminiferous ether; and the eye, or sense-organ of sight, is constructed in such a way that rays of light which falling on any other part of the body produce no appreciable effect, give rise to vivid sensations when they fall upon it.

rther we may, with more or less completeness, dis-
ish in each sense-organ two parts : an **essential** part,
gh which the agent producing the sensation (be it
. a series of sonorous vibrations, a sapid or odorous
ical substance, a change in temperature, or a varia-
n pressure), produces changes in certain structures
n are peculiarly associated with the delicate termina-
of the nerve distributed to the sense-organ ; and an
essory part, not absolutely necessary to the sense
of great usefulness inasmuch as it assists in bringing
agent to bear, in the most efficient way, upon the
tial part. In the case of the eye and ear this acces-
part is extremely complicated, and indeed seems to
the greater part of the whole sense-organ ; in the
of the other senses it is much more simple.

he essential part of each sense-organ is in turn com-
d of minute organs, which upon examination appear
e in reality modified epithelial cells ; and the delicate
inations of the nerve filaments distributed to the
e-organ may, with more or less distinctness, be traced
hese modified cells, in which indeed they seem to end.
se minute organs, these modified epithelial cells, may
poken of as **sense-organules** ; they serve as inter-
iators in each case between the physical agent of the
ation and the sensory nerve. The physical agent is
tself unable to produce in the fibres of the sensory
e those changes which, reaching the brain as nervous
ulses, give rise to the special sensations. Thus, as we
presently see, rays of light falling upon the optic
e cannot give rise to a sensation of sight. The physical
t must act first on the sense-organules, and these in
act upon the filaments of the nerve. Thus light
ng upon the sense-organules, situated in that essential
of the eye called the retina, sets up changes in them,
e changes set up corresponding changes in the delicate
e filaments which with the sense-organules go to
e up the retina, and the changes in the nerve filaments

propagated along the optic nerve to the brain give rise, in the latter, to sensations of sight.

Hence in the essential part of each sense-organ we have to distinguish between the sense-organules, *i.e.*, the modified epithelium, and the terminal expansion of the sensory nerve ; and further, in each sense-organ, there is added to this essential part a more or less complicated accessory part.

Lastly, in all these special sensations, there are certain phenomena which arise out of the structure of the sense-organ, and others which result from the operation of the central apparatus of the nervous system upon the materials supplied to it by the sense-organ.

5. The Skin as a Sense-Organ.—The sense of touch (including that of pressure, heat and cold and pain) is possessed, more or less acutely, by all parts of the free surface of the body, and by the walls of the mouth and nasal passages.

Whatever part possesses this sense consists of a membrane (integumentary or mucous) composed of a deep layer made up of fibrous tissue containing a capillary network, and of a superficial layer consisting of epithelial or epidermic cells, among which are no vessels.

Wherever the sense of touch is delicate, the deep layer is not a mere flat expansion, but is raised up into multitudes of small, close-set, conical elevations (see Fig. 57, p. 191), which are called **papillæ**. In the skin, the coat of epithelial or epidermic cells does not follow the contour of these papillæ, but dips down between them and forms a tolerably even coat over them. Thus, the points of the papillæ are much nearer the surface than the general plane of the deep layer whence these papillæ proceed. Loops of vessels enter the papillæ, and sensory nerve fibres are distributed to them. In some cases the nerve fibre ends in a papilla in a definite organ, in what is called a **tactile corpuscle**, or in a similar body called an **end-bulb**. Each of these organs consists essentially of

al or rounded swelling formed by a modification and gement of the delicate connective tissue ensheathing rve-fibre ; in the middle of the swelling the nerve- itself ends abruptly in a peculiar manner. These s are especially found in the papillæ of those ies which are endowed with a very delicate sense of , as in the tips of ngers, the point of ngue, &c. ; and the æ which contain tac- corpuscles generally in few or no blood- is.

actile corpuscles

most numerously e papillæ of the skin e palmar surface of hand, especially of inger-tips ; they are present, but much numerously, on the ar surfaces of the of the toes, and are nonest on parts of skin where there is air. Each corpuscle s an elongated, bulb- swelling about 75μ inch) in length at nd of the nerve-fibre nich it is attached,

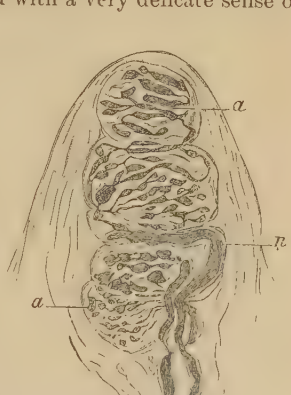


FIG. 109.—TACTILE CORPUSCLE WITHIN A PAPILLA OF THE SKIN OF THE HAND (RANVIER).

n.n, two nerve fibres passing to the corpuscle ; *a.a*, varicose terminations of the nerve fibres inside the corpuscle.

lies with its long axis pointing to the top of the la. The corpuscle consists of a sheath or capsule of ective tissue inside of which are some nucleated cells mixed with connective tissue derived from the outer h. The nerve which supplies the corpuscle ap- hes it at its side, winds once or twice round it and

then enters the body of the corpuscle, where it divides into a number of branches which end in a manner not as yet exactly determined.

End bulbs are found in the papillæ of the skin of the lips and in other situations. They are spheroidal and smaller (40μ in diameter) than the tactile corpuscles. They are not all exactly alike, but the commonest form consists of a thin outer sheath or capsule which is nucleated and encloses a mass of polygonal cells. The nerve-fibre enters the capsule and ends among the cells in its interior.

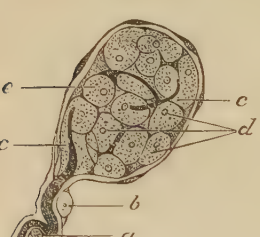


FIG. 110.—END-BULB FROM THE HUMAN CONJUNCTIVA[1] (LONGWORTH).

a, the nerve-fibre; *b*, capsule with nuclei; *c.c*, portions of nerve-fibre inside the end-bulb; *d.c*, cells of the core.

The great majority, however, of the nerve-fibres going to the skin do not end in any such definite organs. They divide in the dermis into exceeding delicate minute filaments, the course and ultimate terminations of which are traced with the greatest difficulty. Some of the finest filaments, however, pass into the epidermis and are there lost among or possibly connected with some of the epidermic cells, especially those of the lower layers.

Another kind of highly specialised nerve-ending is found on the branches of the nerves which supply the skin of the hand and foot, as they pass through the subcutaneous tissue. These are known as **Pacinian corpuscles**, called after Pacini, who first carefully described them. From their position they are not, strictly speaking, sensory endings of nerves in the skin; but they possess

[1] The conjunctiva is the mucous membrane which lines the eyelids and front of the eyeball.

ubtedly some sensory functions, although we do not w what these may be.

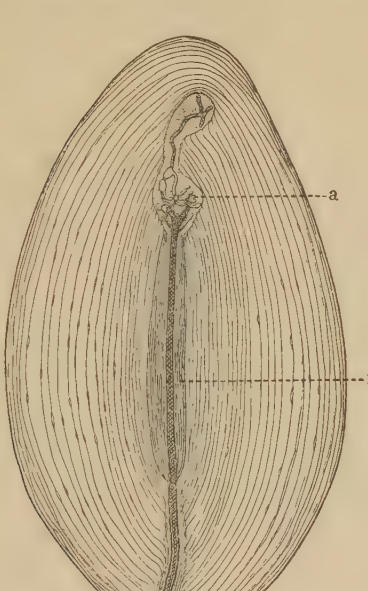


FIG. 111.—A PACINIAN CORPUSCLE FROM A CAT'S MESENTERY. (RANVIER.)

n, nerve-fibre, passing through the core *m*, and terminating at *a*.

The Pacinian corpuscles are long, oval, bulbous ructures of considerable size, averaging $\frac{1}{10}$ of an inch in ngth. They are thus easily visible to the naked eye.

Each corpuscle consists of an elongated central core of glassy-looking material in which the axis of the nerve is embedded and terminates. The core is surrounded by some 30 to 40 capsules made of connective tissue, and placed one outside the other like the layers of an ordinary onion.

It is obvious, from what has been said, that no direct contact takes place between a body which is touched and the sensory nerve,—a thicker or thinner layer of epithelium, or epidermis, being situated between the two. In fact, if this layer is removed, as when a surface of the skin has been blistered, contact with the raw surface gives rise to a sense of pain, not to one of touch properly so called. Thus, in touch, the *essential* part of the sense-organ consists either of certain epithelial or epidermic cells of the general integument or of certain structures contained in the tactile corpuscles, end bulbs, and other similar organs which need not be considered here. These epithelial cells, very slightly modified apparently in the general skin, but more so in the tactile corpuscles and end bulbs, are the sense-organules ; they serve as intermediators between the physical agent—pressure—and the terminal filaments of the sensory nerves. The *accessory* part of the sense-organ of touch is very slightly developed, being chiefly supplied by the variable number and form of the papillæ and the variable thickness and character of the layers of epidermic cells.

(i) **The Sensation of Pressure.**—Mere contact of a single object with the skin exerts a pressure on it which results in a stimulation by means of which we become aware that something is touching us. The power of discriminating pressure and its differences we may call the sense of pressure. The sensitiveness of the various regions of the skin in responding to pressure varies, and the difference may be measured for each part of the skin by determining either what the least weight is which can be just felt when allowed to rest on that part, or else by

rmining the least difference in weight which can be guished between two weights laid in succession on same spot. Experimenting in this way it may be n that the sense of pressure is most acute on the of the forehead and of the back of the hand. The is less acute in the skin of the finger tips. Careful stigation seems to show, with but little doubt, that points on the skin of any part are peculiarly sensi- to pressure. Hence we may perhaps speak of essure spots" in the same way that we do of "heat s" and "cold spots."

) **The Sensations of Heat and Cold.**—The feel- of warmth, or cold, is the result of an excitation ensory nerves distributed to the skin, which are ibly distinct from those which give rise to the sense uch. And it would appear that the heat must be smitted through the epidermic or epithelial layer, to rise to this sensation; for, just as touching a naked e, or the trunk of a nerve, gives rise only to pain, so ing or cooling an exposed nerve, or the trunk of a e, gives rise not to a sensation of heat or cold, but ly to pain. Thus, if the elbow be dipped into a ure of ice and salt, the cold first affects the skin of lbow, giving rise to a sensation of cold at the elbow, afterwards attacks the trunk of the ulnar nerve, h at the elbow lies not very far below the skin; and latter effect is felt as a sensation, not of cold, but of . The pain, moreover, thus caused is not felt in the k of the nerve at the elbow, where the cold is acting, n the parts where the fibres of the nerve end, more cularly in the little and ring fingers.

gain, the sensation of heat, or cold, is relative rather absolute. Suppose three basins be prepared, one with ice-cold water, one with water as hot as can orne, and the third with a mixture of the two. If nand be put into the hot-water basin, and then ferred to the mixture, the latter will feel cold; but

if the hand be kept a while in the ice-cold water, and then transferred to the very same mixture, this will feel warm.

Like the sense of touch, the sense of warmth varies in delicacy in different parts of the body. The cheeks are very sensitive, more so than the lips; the palms of the

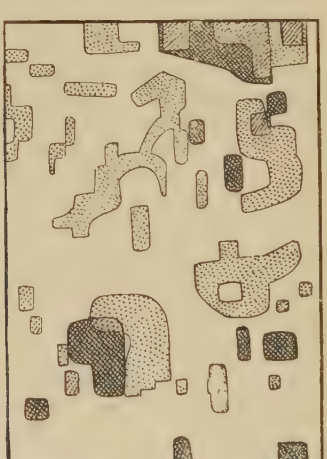


FIG. 112.—OUTLINES OF HEAT SPOTS AND COLD SPOTS. (AFTER GOLDSCHEIDER.)

The heat spots are cross-hatched and dark, the cold spots are dotted and light. In some places the heat spots and cold spots overlap each other.

hands are more sensitive to heat than their backs. Hence a washerwoman holds her flat-iron to her cheek to test the temperature, and one who is cold spreads the palms of his hands to the fire.

The differences in the sensitiveness of the skin to heat and cold at various points may be readily determined by

ning the several points with the blunt end of a wire
e temperature can be kept constant at any desired
e. In this way it is found that some points respond
at but not to cold, others to cold but not to heat,
at we meet with "heat spots" and "cold spots."
accompanying figure shows the distribution of these
in a small area of the skin of the thigh.

) **The Sensation of Pain.**—Pain may be regarded
ie result of an excessive stimulation of any of the
e endings which are concerned in giving rise to
ations. Pain also results from stimulating the trunks
ne nerves leading from those endings to the central
ous system. In the latter case the pain is "referred"
ards to the end of the nerve, as in the experiment of
ng the elbow, described above. The nerves of any
may thus give rise to pain. From this it might
ar that we can scarcely speak of any distinct and
rate "sense" of pain. But there are certain facts
h show that sensations of pain are probably distinct
, though ultimately mixed up with, other sensations.
in many diseases of the nervous system, such as
notor ataxy, the sensitiveness of the skin to touch
be almost entirely wanting, while pain is readily felt.
her, observation shows that the impulses giving rise
in, as also those resulting from heat and cold, pass
the spinal cord on their way to the brain by paths
h are distinct from those which convey the impulses
ting from mere touch.

) **The Localisation of Tactile Sensations.**—Certain
curious phenomena appertain to the sense of touch ;
of these are probably in part due to varying
mical arrangements, to the varying thickness of the
rmis, and to the abundance or scantiness of special
rgans. Not only is tactile sensibility to a single im-
ion much duller in some parts than in others—a cir-
tance which might in many cases be accounted for by
different thickness of the epidermic layer—but the

power of distinguishing double simultaneous impressions is very different. Thus, if the ends of a pair of compasses (which should be blunted with pointed pieces of cork) are separated by only one-tenth or one-twelfth of an inch, they will be distinctly felt as two, if applied to the tips of the fingers; whereas, if applied to the back of the hand in the same way, only one impression will be felt and, on the arm, they may be separated for a quarter of an inch, and still only one impression will be perceived.

Accurate experiments have been made in different parts of the body, and it has been found that two points can be distinguished by the tongue, if only one-twenty-fourth of an inch apart; by the tips of the fingers if one-twelfth of an inch distant; while they may be one inch distant on the cheek or forehead, and even three inches on the back, and still give rise to only one sensation.

6. The Muscular Sense. — What is termed the muscular sense is less vaguely localised than the sensations referred to above in Section 2 (p. 341), though its place is still incapable of being very accurately defined. This muscular sensation is largely the feeling of resistance which arises when any kind of obstacle is opposed to the movement of the body, or of any part of it; and it is something quite different from the feeling of contact or even of pressure.

Lay one hand flat on its back upon a table, and rest a disc of cardboard a couple of inches in diameter upon the ends of the outstretched fingers; the only result will be a sensation of **contact**—the pressure of so light a body being inappreciable. But put a two-pound weight upon the cardboard, and the sensation of *contact* will pass into what appears to be a very different feeling, viz., that of **pressure**. Up to this moment the fingers and arm have rested upon the table; but now let the hand be raised from the table, and another new feeling will make its appearance—that of **resistance to effort**. The

; comes into existence with the exertion of the
s which raise the arm ; and it is the consciousness
exertion which goes by the name of "the muscular

one who raises or carries a weight knows well
that he has this sensation ; but he may be greatly
to say where he has it. Nevertheless, the sense
s very delicate, and enables us to form tolerably
te judgments of the relative intensity of resistances.
ns who deal in articles sold by weight are constantly
d to form very precise estimates of the weight of
rticles by balancing them in their hands ; and in
se, they depend in a great measure upon the mus-
sense.

the muscular sense embraces more than the mere
iousness of the *resistance to effort* involved in lifting
ght. Thus it is a matter within everybody's experi-
hat, even when the eyes are closed, we are perfectly
aware of the *direction and extent of any movement*
y part of the body. Moreover we are equally con-
s of the *position* of any part of the body at any
nt, whether the position is the result of our own
tary movement or the result of the action of some
person who has placed the part in position. In all
cases the muscular sense supplies the basis of our
ledge of the position or of the movements of the
of our body.

e muscular sense is thus essentially concerned with
tions arising from movements whether active or
ve. Now the parts affected by these movements are
ly the following three ; the skin, the muscles and the
ons or ligaments. It has been supposed that the
lses which give rise to the sensations may be largely
to the stimulation of cutaneous nerves resulting from
arying extent to which the skin is put on the stretch
ne movements ; but the arguments in favour of this
are not conclusive. On the other hand we know

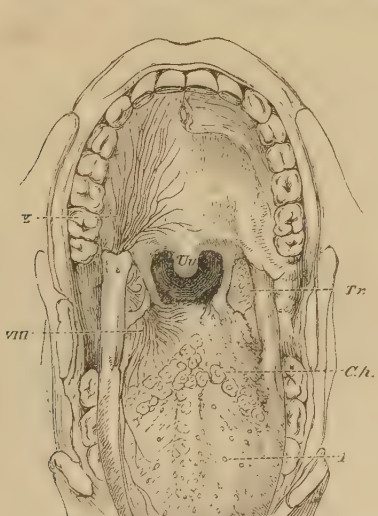
that the muscles themselves possess nerve fibres which are certainly afferent, *i.e.* sensory ; and similarly afferent fibres, connected with extremely minute end-bulbs, are distributed to the tendons. And there is but little doubt that we must look to the impulses generated in these nerves, more especially the nerves of the tendons, as providing the sensations which form the basis of the muscular sense.

7. The Sense of Taste.—The organ of the sense of taste is the mucous membrane which covers the tongue, especially its back part, and the hinder part of the palate. Like that of the skin, the deep, or vascular, layer of the mucous membrane of the tongue is raised up into papillæ ; but these are large, separate, and have separate coats of epithelium. Towards the tip of the tongue they are for the most part elongated and pointed, and are called **filiform** ; over the rest of the surface of the tongue these are mixed with other large papillæ, with broad ends and narrow bases, called **fungiform** ; but towards its root there are a number of larger papillæ, arranged in the figure of a V with its point backwards, each of which is like a fungiform papilla surrounded by a wall. These are the **circumvallate** papillæ (Fig. 113, *C.p.*). The larger of these papillæ have subordinate small ones upon their surfaces.

In both the fungiform and circumvallate papillæ, the cells which are specially concerned in giving rise to sensations of taste are arranged in bulbous groups, somewhat like the leaves in a bud, and hence these groups are known as **taste-buds**. In the circumvallate papillæ these taste-buds lie imbedded in the layers of epithelium which cover the sides of each papilla.

Each "bud" is flask-shaped and consists of an outer wall, made up of elongated cells placed side by side like the staves of a barrel, and leaving an opening at the end of the bud where it comes to the surface of the papilla. The inside of the bud is filled with the true **gustatory cells**,

l side by side into the cavity of the bud. Each of cells is long and very thin, with a large nucleus at iddle point, and each cell has at its outer end a



. 113.—The Mouth widely opened to show the Tongue and Palate.

the uvula; *Tn.* the tonsil between the anterior and posterior pillars fauces; *C.p*, circumvallate papillæ; *F.p*, fungiform papillæ. The e filiform papillæ cover the interspaces between these On the side the tongue is partially dissected to show the course of the fila- of the glossopharyngeal nerve, *VIII.*

ate process, like a stiff cilium (but not vibratile), h projects through the open mouth of the bud.

e papillæ are very vascular, and they receive nervous ents from two sources, the one the nerve called

glossopharyngeal, the other the **gustatory**, which is a branch of the **fifth** nerve (see Lesson XI.). The latter chiefly supplies the front of the tongue, the former its back and the adjacent part of the palate; and there is reason to believe that different taste sensations are supplied by the two nerves.

The peculiar cells in the taste-buds are the sense-organules of taste, and, with the delicate terminations of the glossopharyngeal and gustatory nerve which may be traced to them, constitute the *essential* parts of the organ

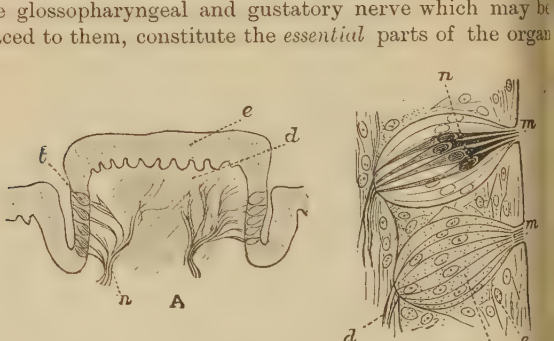


FIG. 114.—DIAGRAM OF A CIRCUMVALLATE PAPILLA, AND OF TASTE-BUDS

A, A circumvallate papilla cut across; *e*, epidermis; *d*, dermis; *b* taste-buds; *n*, nerve fibres.

B, Two taste buds; *e*, epidermis; *d*, dermis; *c*, the outer or cover cells shown in the lower bud; *n*, four inner cells with processes; *m* processes projecting at mouth of buds.

of taste. The tongue itself, which by its movements brings the sapid substances into immediate contact with these modified epithelium cells, may be regarded as the accessory part.

The great majority of the sensations we call taste, however, are in reality complex sensations, into which smell and even touch, and the temperature sense, as in the sensation of cold produced by peppermint, largely enter. When the sense of smell is interfered with, as when the

held tightly pinched, it is very difficult to distinguish ste of various objects. An onion, for instance, es being shut, may then easily be confounded with le. This explains the not uncommon device of g the nose when taking nauseous medicine.

he so-called "tastes" which are thus affected by sence of smell ought rather to be spoken of as urs" than as tastes. They are distinctly due to oriferous particles the substances emit, and thus are in the habit of "sniffing" a glass of wine in o appreciate what they call its taste. True taste is ndent of smell, as in the case of sugar or quinine. we come to investigate the matter closely, we find he various real tastes may be arranged under four these are—sweet, bitter, sour or acid, and salt. tastes are not excited equally all over the surface tongue. Thus the tip is most sensitive to sweet nces, and the back to bitter, while the sides of ngue most readily respond to acids.

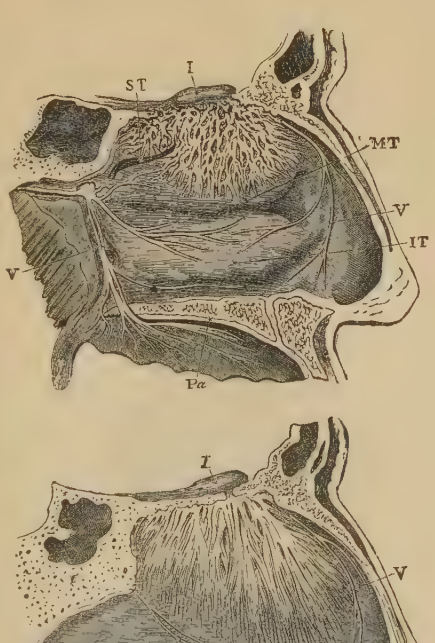
sense of taste is most acute at medium temperatures, as 20°—30° C. (68°—95° F.), and substances to be must be in solution.

The Sense of Smell.—The organ of the sense of is the delicate mucous membrane which lines the part of the nasal cavities. In this part the mucous rane is distinguished from the rest of the mucous rane of these cavities—firstly, by the character of lls and by possessing no cilia; secondly, by receiving e nervous supply from the olfactory, or first, pair of ral nerves (see Lesson XI.), as well as a certain er of filaments of the fifth pair, whereas the rest e mucous membrane is supplied from the fifth pair

h nostril leads into a spacious nasal chamber, ated, in the middle line, from its fellow of the other by a partition, or **septum**, formed partly by cartilage artly by bone, and continuous with that partition

which separates the two nostrils one from the other. Below, each nasal chamber is separated from the cavity of the mouth by a floor, the bony palate (Figs. 115 and 116); and when this bony palate comes to an end, the partition is continued down to the root of the tongue by a fleshy curtain, the soft palate, which has been already described. The soft palate and the root of the tongue together, constitute, under ordinary circumstances, a movable partition between the mouth and the pharynx; and it will be observed that the opening of the larynx, the *glottis*, lies behind the partition; so that when the root of the tongue is applied close to the soft palate no passage of air can take place between the mouth and the pharynx. But in the upper part of the pharynx above the partition are the two hinder openings of the nasal cavities (which are called the **posterior nares**) separated by the termination of the septum; and through these wide openings the air passes, with great readiness, from the nostrils along the lower part of each nasal chamber to the glottis, or in the opposite direction. It is by means of the passages thus freely open to the air that we breathe, as we ordinarily do, with the mouth shut.

Each nasal chamber rises, as a high vault, far above the level of the arch of the posterior nares—in fact, about as high as the depression of the root of the nose. The uppermost and front part of its roof, between the eyes, is formed by a delicate horizontal plate of bone, perforated like a sieve by a great many small holes, and thence called the **cribriform** plate (Fig. 116, *Cr.*). It is this plate (with the membranous structures which line its two faces) alone which, in this region, separates the cavity of the nose from that which contains the brain. The olfactory lobes, which are directly connected with, and form indeed a part of, the brain, enlarge at their ends, and their broad extremities rest upon the upper side of the cribriform plate, sending through it immense numbers of



G. 115.—Vertical Longitudinal Sections of the Nasal Cavity.

ne upper figure represents the outer wall of the left nasal cavity ; the er figure the right side of the middle partition, or septum (*Sp.*) of the e, which forms the inner wall of the right nasal cavity. *I*, the olfac- nerve and its branches ; *V*, branches of the fifth nerve ; *Pa.* the ate, which separates the nasal cavity from that of the mouth ; *S.T*, superior turbinal bone ; *M.T*, the middle turbinal ; *I.T*, the inferior binal. The letter *I* is placed in the cerebral cavity ; and the partition which the olfactory lobe rests, and through which the filaments of the ctory nerves pass, is the cribriform plate.

delicate filaments, the olfactory nerves, which are distributed as follows (Fig. 115) :—

On each wall of the septum the mucous membrane forms a flat expansion, but on the side walls of each nasal cavity it follows the elevations and depressions of the inner surfaces of what are called the **upper** and **middle turbinal**, or spongy **bones.** These bones are called

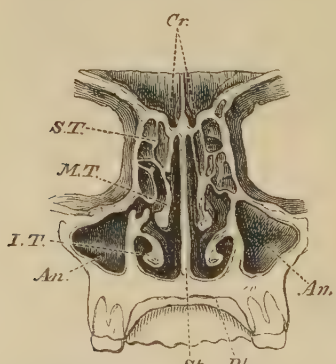


FIG. 116.—A TRANSVERSE AND VERTICAL SECTION OF THE OSSEOUS WALLS OF THE NASAL CAVITY TAKEN NEARLY THROUGH THE LETTER *I* IN THE FOREGOING FIGURE.

Cr. the cribriform plate ; *S.T*, *M.T*, the chambered superior and middle turbinal bones on which and on the septum (*Sp.*) the filaments of the olfactory nerve are distributed ; *I.T*, the inferior turbinal bone ; *Pl.* the palate ; *An.* the *antrum* or chamber which occupies the greater part of the maxillary bone and opens into the nasal cavity.

spongy because the interior of each is occupied by air cavities separated from each other by very delicate partitions only, and communicating with the nasal cavities. Hence the bones, though massive-looking, are really exceedingly light and delicate, and fully deserve the appellation of spongy (Fig. 116).

Over these upper and middle turbinal bones, and on

sides of the septum opposite to them, the mucous brane is specially modified, and receives the name of **tory mucous membrane**; and it is to this tory mucous membrane that the filaments of the tory nerve passing through the cribriform plate are ibuted.

ere is a third light scroll-like bone distinct from these nd attached to the maxillary bone, which is called nferior turbinal, as it lies lower than the other two, imperfectly separates the air passages from the r olfactory chamber (Fig. 115). It is covered by ordinary ciliated mucous membrane of the nasal ge, and receives no filaments from the olfactory e.

the non-olfactory part of the nasal mucous mem- e the epithelium cells are ordinary ciliated epithelium (see p. 284); but in the olfactory part the cells not lose their cilia, but become peculiarly modified. y of them become very slender and rod-shaped, and elicate terminations of the olfactory nerve filaments ar to end in these modified epithelial cells, which ed are the sense-organules of the organ of smell. olfactory mucous membrane, with the filaments of olfactory nerve ending in it, thus constitutes the ntial part of the organ.

ne cells of the olfactory mucous membrane are of two s, and somewhat similar to those composing a taste- ; but their arrangement is different. Thus one kind ell is long, slender and rod-shaped, with a large eus towards its inner end. The cells of the second are also thin and rod-like at their inner ends, but nd the nucleus, the outer end is wide and columnar. cells of the first kind, which are the most numerous, upposed to be those which are specially concerned in g rise to the sensations of smell. The olfactory ous membrane is made up of a mass of these two kinds ll, placed side by side and intermixed. (Fig. 117.)

The accessory part of the organ of smell may be described as follows :—

From the arrangements which have been described, it is clear that, under ordinary circumstances, the gentle inspiratory and expiratory currents will flow along the comparatively wide, direct passages afforded by so much of the nasal chamber as lies below the middle turbinal; and that they will hardly move the air enclosed in the narrow interspace between the septum and the upper and middle spongy bones, which is the proper olfactory chamber.

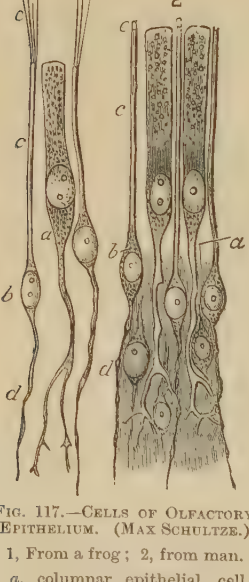


FIG. 117.—CELLS OF OLFACTORY EPITHELIUM. (MAX SCHULTZE.)

1, From a frog; 2, from man.

a, columnar epithelial cell; *b*, olfactory rod-cell; *c*, outer limb, *d*, inner limb of olfactory cell, the former being prolonged at *e* into fine hairs, the latter being continuous with a nerve filament from the olfactory nerve.

If the air currents are laden with particles of odorous matter, these can only reach the olfactory membrane by diffusing themselves into this narrow interspace; and, if there be but few of these particles, they will run the risk of not reaching the olfactory mucous membrane at all, unless the air in contact with it be exchanged for some of the odoriferous air. Hence it is that, when we wish to perceive a faint odour more distinctly, we "sniff" or snuff up the air. Each sniff is a sudden inspiration, the effect of which must reach the air in the olfactory chamber at the same time as, or even before, it affects that at the

ils ; and thus must tend to draw a little air out of chamber from behind. At the same time, or immediately afterwards, the air sucked in at the nostrils ing with a sudden vertical rush, part of it must tend w directly into the olfactory chamber, and replace hus drawn out.

e loss of smell which takes place in the course of a cold may, in part, be due to the swollen state of ucous membrane which covers the inferior turbinal s, impeding the passage of odoriferous air to the ory chamber.

ry little is known of the physiology of smell, and s have not so far been classified except as agreeable e reverse ; but recent observations seem to show that ch more detailed classification is possible, Everyday ience shows that the sense is extremely delicate, most minute amount of odoriferous matter, such as , serving to excite it.

The Ear and the Sense of Hearing.—The ear, or of the sense of hearing, is very much more complex either of the sensory organs yet described ; and in it the essential and the accessory parts are much more y developed.

e essential part, on each side of the head, consists, antially, of a very peculiarly-formed membranous This bag, when the ear first begins to be formed, is ple round sac, but it subsequently takes on a very licated form, and becomes divided into several parts, n receive special names. It is lodged in a cavity of spondingly intricate shape, hollowed out of a solid of bone (called from its hardness *petrosal*), which s part of the temporal bone, and lies at the base e skull. The sac, however, does not completely fill avity, so that a space is left between the bony walls he contained sac. This space, which is continuous und the sac, being interrupted at certain places only e the membranous sac is attached to the bony walls,

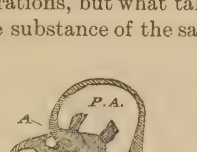
contains a fluid provided by the lymphatics of the neighbourhood, and called **perilymph**.

The membranous sac, the walls of which consist chiefly of connective tissue, is lined by an epithelium, and contains a fluid of its own called **endolymph**. The perilymph, it will be understood, is quite distinct from the endolymph, the two fluids being separated by the walls of the membranous sac.

Over a great part of the interior of the membranous sac the epithelium is simple in character, but at certain places to be presently described it assumes special features, being greatly thickened, and bearing hair-like processes, or being otherwise modified, so as to be easily affected by even such slight movements as the vibrations which produce sound. Where these patches or tracts of modified or **auditory epithelium**, as it is called, exist, the membranous sac is more closely attached to the bony walls; and branches of the eighth, acoustic or auditory, nerve (see Lesson XI.), passing through channels in the bony walls, through the tissue attaching the membranous sac to the bony walls, and through the wall of the membranous sac itself, come into peculiar relation with, and end in, or among, the cells of these patches of auditory epithelium. It is only to the places where the epithelium is thus modified that filaments of the auditory nerve are distributed.

What takes place in hearing may briefly be stated as follows. The vibrations set up by a sounding body are conducted, by the accessory apparatus to be presently described, to the perilymph, and from thence through the walls of the membranous sac to the endolymph. As the vibrations travelling along the endolymph reach those particular places where the epithelium is modified, and where the filaments of the auditory nerve end, they in some way or other affect the epithelium cells. Through the intermediation of these cells the delicate endings of the auditory nerve are stimulated, so that molecular

ges are set up in the substance of the nerve, and
mitted along the nerve from particle to particle,
they reach that part of the brain the molecular
rbance of which gives rise to sensations of sound.
us, until the auditory epithelium is reached, that
takes place in the ear when we hear a sound is
y a transmission of vibrations of the same order as
which are produced by the sounding body; but the
sses which intervene between the epithelium and
rain are not of the same kind; here there is no trans-
ion of such vibrations, but what takes place is a series
anges of nerve substance of the same order as, though



. 118.—The Membranous Labyrinth, twice the natural size.

the *Utricle*, or part of the vestibular sac, into which the semi-
lar canals open; *A. A. A*, the ampullæ; *P.A*, anterior vertical semi-
lar canal; *P. V*, posterior vertical semicircular canal; *H*, horizontal
circular canal. The saccule is not seen, as in the position in which
abyrinth is drawn the saccule lies behind the utricle. The white
es on the ampullæ of the posterior, vertical, and horizontal canals
ate the cut ends of the branches of the auditory nerve ending in
ampullæ; the branches to the ampulla of the anterior vertical
are seen in the spaces embraced by the canal, as is also the branch
e utricle.

aps not exactly like, those which are set up by the
on of a stimulus on any other nerve.

) **The Membranous Labyrinth.**—The membranous
as we have said, is not simple but complicated;
onsists of several parts. In the first place there
a somewhat oval sac, called the **utricle** (Fig.
Ut.) into which open three hoop-like, semicircular
ls. Of these two are placed vertically, one directed

anteriorly, the other posteriorly, and are hence called the **anterior** (*P.A*) and **posterior** (*P.V*) **vertical semicircular canals.** The third is placed horizontally and directed outwards, hence it is called the **exterior horizontal semicircular canal** (Fig. 118, *H*). It will be observed that the three canals thus lie in the three directions of space; this has nothing to do with judging

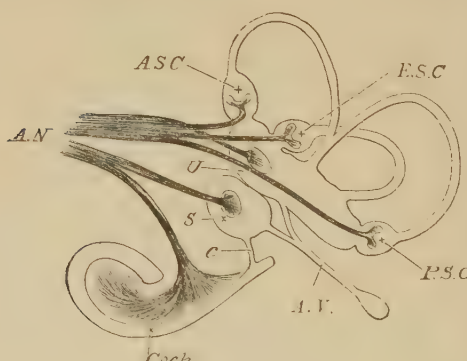


FIG. 119.

Diagram to illustrate the endings of the auditory nerve in the membranous labyrinth and cochlea. N.B. *The drawing is diagrammatic.*

A.N. auditory nerve dividing into several branches, and ending:—at *A.S.C.* in the ampulla of the anterior vertical semicircular canal: *P.S.C.* do. posterior vertical: *E.S.C.* do. external horizontal: *U.* in the utricle *S.* in the saccule. *Coch.* the ending all along the canalis cochlearis; *A.V.* canal uniting the interior of utricle with that of saccule. *C.* canal joining the saccule to the canalis cochlearis.

the directions of sound, but may possibly have a relation to other functions of the canals. Each of these three hoops is dilated at one of its two ends, where it opens into the utricle, into what is called an **ampulla** (Fig. 118, *A*, *A*, *A*), the other end having no ampulla. Thus there is one ampulla to each canal. Those ends of the two vertical canals which are not dilated into ampullæ

together (Fig. 119), before they open into the
le.

each ampulla is a ridge or crest, called **crista**
stica, placed crosswise, and projecting into the
of the canal. Each crest is formed partly by an
ing and thickening of the connective tissue wall of
mpulla, and partly by a thickening of the epithelium,
here has the peculiar characters already referred
A similar but oval patch of thickened, modified,
ory epithelium, with a thickening of the wall beneath
s found in the utricle itself; this is called a
cula acustica.

ttached to the utricule is a similar smaller sac (form-
another division of the primitive membranous bag)
ed the **saccule**, on the walls of which is a similar
ded patch of modified epithelium, or *macula*. The
y of the saccule is cut off from that of the utricle,
pt for a curious roundabout connection by means of a
ow canal (Fig. 119, *A.V.*).

he utricle and saccule with the three semicircular
ls receive the name of the **membranous laby-**
h. It will be remembered that this membranous
rinth, filled with endolymph, lies in an intricate cavity
bony walls called the **osseous labyrinth**, of which
part which contains the saccule and utricle is known
he **vestibule**, and that between the walls of the
y and the membranous labyrinth, which correspond
ely but not wholly in form, is a space filled with
lymph.

Branches of the auditory nerve pass to this mem-
nous labyrinth and send fibres (Fig. 119) to the three
ts of the three ampullæ, to the patch on the utricle,
to the patch on the saccule. In each crest and each
h the epithelium is thickened and modified, and al-
gh the crests are slightly different in structure from
patches, the general features are the same in all.
reas over the rest of the inside of the membranous

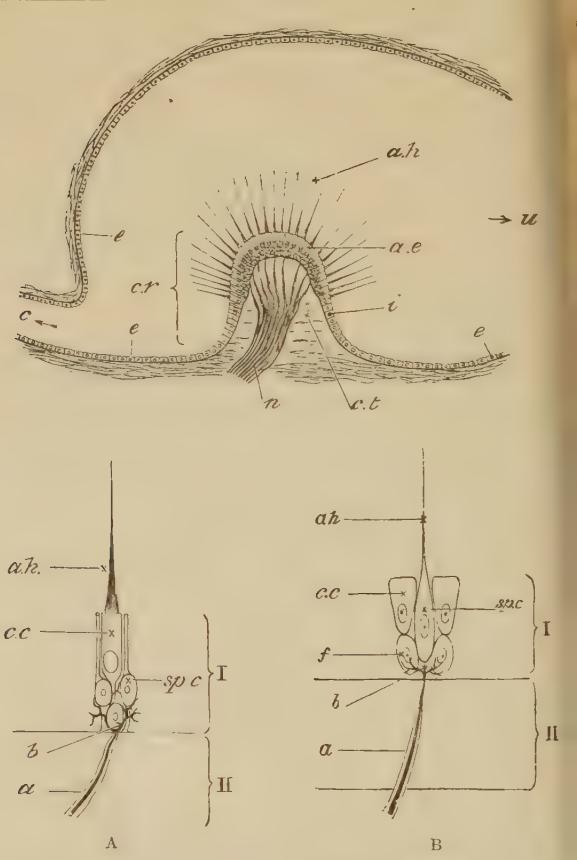


FIG. 120.—LONGITUDINAL SECTION OF AMPULLA, CUTTING THE CREST CROSSWISE (SOMEWHAT DIAGRAMMATIC).

c, one end of the ampulla forming the semicircular canal, *u*, the other end opening into the utricle; *e*, ordinary epithelium lining the greater part of the ampulla; *cr*, the crest with *a.e*, auditory epithelium; *a.h* auditory hairs; *c.t*, connective tissue support to the auditory epithe

ath the epithelium consists (Fig. 120, *e*) of a single
of low, rather flat cells, in the crests and patches
lls lie several deep, and are of a peculiar form.
are conical or cylindrical, and some are spindle-
. and either the one or the other, or, according to
thors, both, bear stiff hair-like filaments (Fig. 120,
B, *a.h*) projecting into the cavity of the labyrinth.
filaments, often called auditory hairs, appear at first
o resemble cilia, but they are stiff, and unlike cilia
o active movement of their own. They are longer
ore conspicuous in the crests of the ampullæ than
patches of the utricle and saccule. The fibres
auditory nerve may be traced through the connec-
ssue wall of the crest or patch into the epithelium,
they break up into a delicate network among the
Fig. 120, *A*, *B*, *b*); but it is not as yet exactly de-
ned how the filaments of this network end, whether
ctually join the conical cells, or the spindle cells, or
y lie in contact with them.

wever this may be, it is very clear that the vibrations,
ves of sound, reaching the ear from some sounding
in passing along the endolymph, set in movement
hairs, very much as waves of the wind set in move-
stalks of standing corn, and that the movements of
irs, by help of the cells to which the hairs belong,

---

n, fibres of the auditory nerve passing into the auditory epithe-
f, epithelium intermediate between the auditory epithelium and
inary epithelium of the rest of the ampulla.

d B, Diagrams to illustrate the character of the cells of the auditory
ium, and the two views taken as to the relation of the auditory
o the cells. In both A and B, I is the auditory epithelium, II the
tive tissue on which it rests, and *a*, a fibre of the auditory nerve
through II, and dividing into fine branching filaments in I, at *b*.
c.c, cylindrical cells bearing auditory hairs, *a.h*; each cell bears
o of fine hairs which adhere together as a long narrow cone; *sp.c*,
-shaped cells, not bearing hairs.
c.c, cylindrical cells not bearing hairs, *sp.c* spindle-shaped cells
the auditory hair, *d*, and supposed to be connected with the
ilaments; *f*, other supporting cells.
oth A and B, the fibre, *a*, of the auditory nerve passes into the
ium, and ends in fine branches, *b*.

excite the delicate filaments of the nervous network below, and so set up disturbances or impulses which pass along the auditory nerve to the brain.

In the utricle and saccule where, as has been said, the hairs are not so conspicuous, the endolymph contains a number of small calcareous particles called **otoliths**, and these are supposed by many to be of use in increasing the effect of the waves in the endolymph. In bathing in a tolerably smooth sea, on a rocky shore, the movement of the little waves as they run backwards and forwards is hardly felt by any one lying down; but in bathing on a sandy and gravelly beach the pelting of the showers of little stones and sand, which are raised and let fall by each wavelet, makes a very definite impression on the nerves of the skin. And it may be that the movements of these otoliths in a similar way produce a greater effect on the epithelium than would the mere waves of the endolymph: but in some of the lower animals these minute particles are replaced by one large stone which seems rather to act as a damper; so that the exact use of the otoliths must be left at present undecided.

(ii) **The Cochlea.**—An important part of the essential apparatus yet remains to be described, and that is the **cochlea.**

Connected with the saccule by a narrow canal is an extension of the original membranous sac, in the form of a long tube closed at the end (Fig. 119, *Coch.*). This cochlear tube, like the parts of the membranous sac already described, is lined with epithelium, contains endolymph, and is lodged in a bony cavity filled with perilymph. So far it resembles the labyrinth, but in many other respects it is very different.

In the first place, in the labyrinth, with the exception of the vestibule, the membranous sac very closely follows the contour of the bony walls, so that in a section of a semicircular canal, for instance, the membranous canal presents a circular contour lying in the

r circular contour of the bony canal. But in the
a, on the contrary, the contour of the cochlear tube
ng its whole length, totally different from that of
ontaining cavity; for, in transverse section, while
ntour of the containing cavity is almost circular,
f the cochlear tube itself is nearly triangular. The
ar tube in fact is, in shape, what is often called
ular (as when we speak of a triangular file), but
l be called *trihedral*; that is to say it has three sides
es (and three edges); one of the sides is however
t but convex, *i.e.*, bulges somewhat outwards.
the second place, in the labyrinth, the sac is for the
part free from the bony walls, being attached only at
laces where the nerve fibres pass into it, and, more
ly, at some few other points; but in the cochlea, on
ntrary, the cochlear tube closely adheres to the bony
along the whole length of the tube, in two regions,
ly, over the whole of that face of the trihedral tube
has just been described as being convex, and at
dge opposite. Take a round ruler, make a paper
which just fits it, and close the case at one end.
pare down the ruler on two sides until it has two
aces meeting at an edge, and slide it into the case,
at it does not quite reach the closed end. The ruler,
were hollow, would represent the cochlear tube; and
l be observed that it divides the cavity of the case
two passages, which are quite distinct from each
, except at the end of the case to which the ruler does
each. In a similar way, the cochlear tube, containing
lymph, divides the cavity containing perilymph, in
h it lies, into two passages, called **scalæ**, which are
in section (Fig. 121) to be placed one above and the
below the triangular cavity of the cochlear tube
, and which communicate with each other at the far
f the cochlear tube, but not elsewhere.
one point, however, the comparison with the ruler
ts case is not exact. The cochlear tube is not nearly

so wide as the containing cavity; and the sharp edge opposite the convex adherent face would not be in direct connexion with the bony walls, were it not for a bony ledge which, projecting from the bony walls towards the thin edge of the cochlear tube, is united to it by membrane and thus forms a partition or **septum**, which separates the two scalæ in the region where the cochlear tube itself would otherwise leave a communication between them.

In the third place, the cochlear tube is not straight or

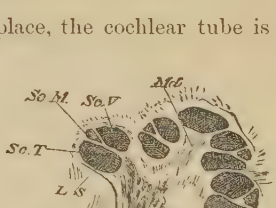


FIG. 121.—A SECTION THROUGH THE AXIS OF THE COCHLEA, MAGNIFIED THREE DIAMETERS.

Sc.M, scala media; *Sc.V*, scala vestibuli; *Sc.T*, scala tympani; *L.S*, lamina spiralis; *Md*. bony axis, or modiolus, round which the scalæ are wound; *C.N*, cochlear nerve.

even simply curved, but is twisted up on itself, into a spiral of two and a half turns. In these twists it is accompanied by the cavities above and below it, and also by the septum spoken of above, which thus takes a spiral course, and is spoken of as the **lamina spiralis** (Figs. 121, 122, *l.s*). The whole arrangement somewhat resembles the shell of a snail; hence the name. All along the spiral the edge of the cochlear tube attached to the lamina spiralis is directed inwards and the convex face outwards; so that when a section is made through the axis of the spiral a succession of rounded spaces are cut through, each space

biting, above and below, the somewhat half-moon-ed section of a *scala*, the two scalæ being separated e outer side, by the cochlear tube, and, on the inner, he lamina spiralis (Fig. 121).

e triangular cavity which, as we have seen, contains lymph, and is continuous with the sacculus, is called **canalis cochlearis**, or **scala media** (because it lies een the two other cavities). The upper of the two ies containing perilymph, when traced down to the m of the spiral, is found to be continuous with the y containing perilymph which surrounds the vestibule the utriculus and sacculus); hence it is called the **a vestibuli**. The lower cavity, when similarly traced he bottom of the spiral, ends against the inner wall of rt of the ear to be presently described, called the *anum*, by an opening, called the **fenestra rotunda**, h is closed by a membrane. Hence this lower cavity lled the **scala tympani**. Thus the scala vestibuli scala tympani begin at different points, and are rated along their whole course by the cochlear tube the lamina spiralis except at the very tip of the spiral, e these latter end; here the two scalæ are prolonged nd the cochlear tube and join together, forming a non space, as seen at the top of Fig. 121.

he vibrations of sound are brought, as we shall see, e perilymph chamber of the vestibule, whence they d on the one hand over the semicircular canals, and he other into the scala vestibuli. Passing upwards, he spiral along the scala vestibuli, they enter at the nit the scala tympani, along which they descend, and ventually lost at the fenestra rotunda in which that ends.

) **The Organ of Corti.** But besides this peculiar gement of the perilymph chamber, there are other still more important differences between the cochlea he labyrinth.

e auditory nerve is, as we have seen, distributed to

certain parts only of the membranous labyrinth, namely, to the crests of the ampullæ and to the patches on the utriculus and the sacculus ; but, in the case of the cochlea, fibres, running in canals excavated in the bony core of the spiral, and in the lamina spiralis (Fig. 122, *A.N*) run to and end in the canalis cochlearis along its whole length, from the bottom to the top of the spiral, Fig. 119, *Coch.* And the mode of ending of these nerves is very peculiar.

If we examine a section of one of the spirals of the cochlea (Fig. 122), we see that the upper side of the cochlear tube (that which separates it from the scala vestibuli) is formed by a thin membrane (called the **membrane of Reissner**, Fig. 122, *m.R*) lined internally by simple epithelium. The outer convex side of the cochlear tube, that side by which it is firmly attached to the bony wall, is also lined internally by simple epithelium. Neither here nor in the membrane of Reissner do any fibres of the auditory nerve end. But the remaining side of the tube, that which looks towards the scala tympani, possesses on its inner face, along the whole length of the tube, from the bottom to the top of the spiral a very remarkable and strangely modified epithelium ; and, along the whole length of the tube, fibres of the auditory nerve pass into and end among the cells of this epithelium, which is spoken of as the **organ of Corti.** (Fig. 122, *O.C.*)

The membrane which separates the cavity of the cochlear tube from the scala tympani, and on which the organ of Corti is placed, is of a peculiar character, specially adapted for being thrown into vibrations, and is called the **basilar membrane.** The organ of Corti itself consists of, in the first place, the so-called **rods of Corti**, peculiarly shaped long bodies, which are seen in section leaning, as it were, against each other. There is an inner row of these and an outer row all along the spiral, each row consisting of several (four to six) thousands of rods. On the inside and on the outside of the rods are

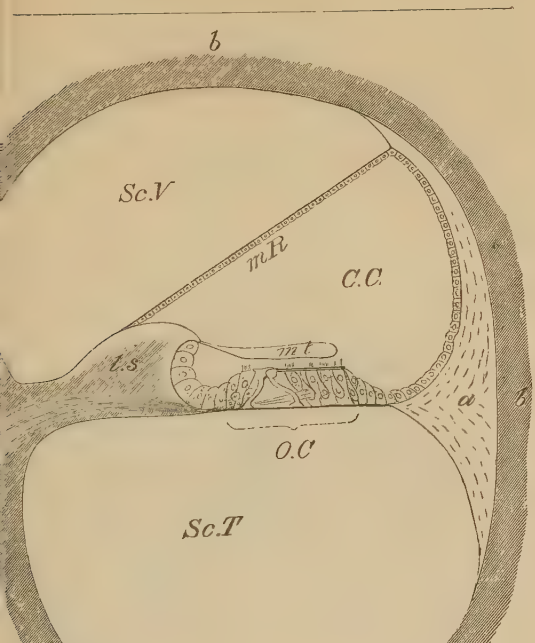


FIG. 122.—SECTION OF COIL OF COCHLEA.

V, scala vestibuli; *Sc.T*, scala tympani; *C.C.* canalis cochlearis, or
, media; *O.C*, organ of Corti; *m.R*, membrane of Reissner, *m.t*,
brana tectoria (a gelatinous membrane overlying the organ of Corti,
supposed to act as a damper). *A.N*, fibres of the auditory nerve
ning in *l.s*, the lamina spiralis, and ending in the organ of Corti;
nnective tissue cushion to which the basilar membrane is attached
he outside; *b*, bony walls.

he figure has, for simplicity's sake, been made somewhat diagram-
c. The lamina spiralis has been drawn too short; the proportions
he lamina spiralis and the scalæ are more exactly rendered in Fig. 121.

very peculiar epithelial cells, also arranged into rows, each row consisting of several thousand cells. Each of these cells bears short hairs on its free surface, hence they are called hair-cells, inner and outer ; and the auditory nerves passing through the lamina spiralis, reach the cochlear tube along the whole length of the spiral, and end in

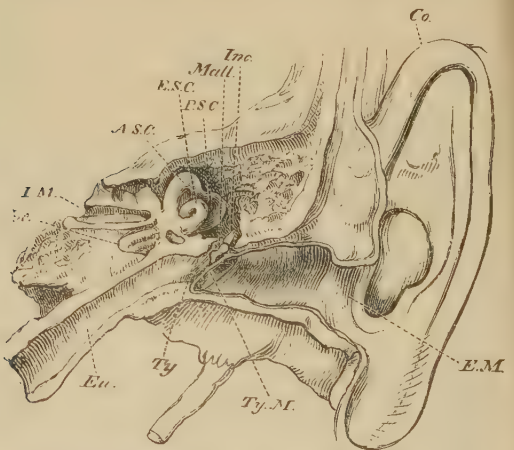


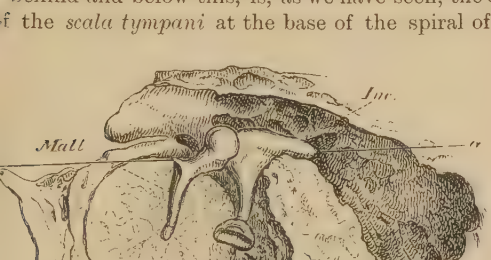
Fig. 123. Transverse Section through the Side Walls of the Skull to show the Parts of Ear.

Co. Concha or external ear ; *E.M*, external auditory meatus ; *Tu.M*, tympanic membrane ; *Inc. Mall.* incus and malleus ; *A.S.C*, *P.S.C*, *E.S.C*, anterior, posterior, and external semicircular canals ; *Coc.* cochlea ; *Eu.* Eustachian tube ; *I.M*, internal auditory meatus, through which the auditory nerve passes to the organ of hearing.

filaments which are lost in the organ of Corti, but are probably connected with the hair-cells.

(iv) **The Bony Labyrinth.**—These essential parts of the organ of hearing, the membranous labyrinth and the canalis cochlearis, are, we have seen, lodged in chambers of the petrous part of the temporal bone.

the fresh state, this collection of chambers in the
is bone is perfectly closed ; but, in the dry skull,
are two wide openings, termed **fenestræ**, or win-
on its outer wall ; *i.e.*, on the side nearest the
le of the skull. Of these fenestræ, one, termed
is (the oval window), is situated in the wall of the
ular cavity ; the other, **rotunda** (the round win-
behind and below this, is, as we have seen, the open
f the *scala tympani* at the base of the spiral of the



4.—The Membrane of the Drum of the Ear, with the small
nes of the Ear seen from the Inner Side; and the Walls
the Tympanum, with the Air-cells in the Mastoid Part of
e Temporal Bone.

petrous part of the temporal bone containing the labyrinth is sup-
to be removed, the foot-plate of the stapes having been detached
he fenestra ovalis.
mastoid cells ; *Mall.* malleus ; *Inc.* incus ; *St.* stapes ; *a b*, lines
through the horizontal axis on which the malleus and incus turn.

a. In the fresh state, each of these windows or
ræ is closed by a fibrous membrane, continuous with
eriosteum of the bone.
fenestra rotunda is closed by membrane only ; but
ed to the centre of the membrane of the *fenestra*
so as to leave only a narrow margin, is an oval
of bone, part of one of the little bones to be de-
d shortly.

(v) **The Middle Ear.**—The outer wall of the internal ear is still far away from the exterior of the skull. Between it and the visible opening of the ear, in fact, are placed in a straight line, first, the drum of the ear, or **tympanum**; secondly, the long external passage, or **meatus** (Fig. 123).

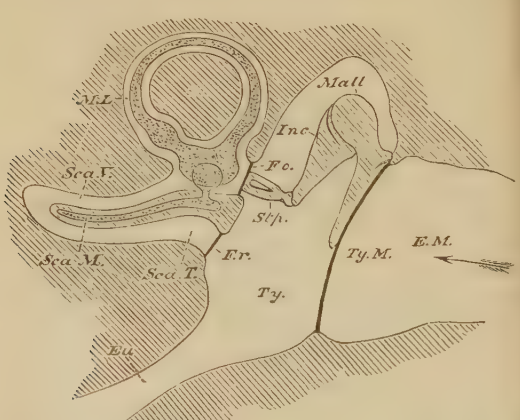


FIG. 125.—A DIAGRAM ILLUSTRATIVE OF THE RELATIVE POSITIONS OF THE VARIOUS PARTS OF THE EAR.

E.M, external auditory meatus; *Ty.M*, tympanic membrane; *Ty.* tympanum; *Mall.* malleus; *Inc.* incus; *Stp.* stapes; *F.o*, fenestra ovalis; *F.r.* fenestra rotunda; *Eu.* Eustachian tube; *M.L*, membranous labyrinth, only one semicircular canal with its ampulla being represented; *Sca.V*, *Sca.T*, *Sca.M*, the scalæ of the cochlea, which is supposed to be unrolled.

The drum of the ear and the external meatus, which together constitute the middle ear, would form one cavity, were it not that a delicate membrane, the tympanic membrane (*Ty.M*, Fig. 123), is tightly stretched in an oblique direction across the passage, so as to divide the comparatively small cavity of the drum from the meatus.

membrane of the tympanum thus prevents any
nication, by means of the meatus, between the drum
external air, but such a communication is pro-
hough in a roundabout way, by the Eustachian
Fu. Fig. 123), which leads directly from the fore
the drum inwards to the roof of the pharynx,
it opens. (See also Fig. 69.)

The Auditory Ossicles.—Three small bones, the
y ossicles, lie in the cavity of the tympanum.
these is the **stapes**, a small bone shaped like a
It is the foot-plate of this bone which, as already
ned, is firmly fastened to the membrane of the
ovalis, while its hoop projects outwards into the
nic cavity (Fig. 124).

ther of these bones is the **malleus** (*Mall.* Figs.
24, 125), or hammer-bone, a long process, the so-
handle, of which is fastened to the inner side of the
nic membrane (Fig. 124) ; while a very much smaller
s, the *slender process*, is fastened, as is also the body
malleus, to the bony wall of the tympanum by
nts. The rounded surface of the head of the
s fits into a corresponding hollowed surface in the
a third bone, the **incus** or anvil bone, thus
g a joint of a somewhat peculiar character. The
nas two processes ; of these one, the shorter, is
ntal, and rests upon a support afforded to it by the
f the tympanum ; while the other, the longer, is
l, descends almost parallel with the long process of
lleus, and articulates[1] with the stapes (Figs. 124
5).

three bones thus form a movable chain between
nestra ovalis and the tympanic membrane. The
s and incus are, by the peculiar joint spoken of
articulated together in such a manner that they

nute bone, the *os orbiculare*, intervenes between the end of the
f the incus and the stapes, so that the stapes is in reality articu-
h the os orbiculare, which in turn is fastened to the process of
. For simplicity's sake, mention of this is omitted above.

may practically be considered as forming one bone which turns upon a horizontal axis. This axis passes through the horizontal process of the incus and the slender process of the malleus, and its ends rest in the walls of the tympanum. Its general direction is represented by the line *a b* in Fig. 124, or by a line perpendicular to the plane of the paper, passing through the head of the malleus in Fig. 125.

The two bones may be roughly compared to two spokes of a wheel, of which the axle is represented by the axis just described: it should be added, however, that one spoke, the incus, is shorter than the other, and that the movement of the two spokes is limited to a very small arc of a circle.

When the membrane of the drum, thrown into vibration by some sound, moves inwards and outwards in its vibrations, it necessarily carries with it, in each inward and outward movement, the handle of the malleus which is attached to it. But with each inward and outward movement of the handle of the malleus, the long process of the incus also moves inward and outward, carrying with it the stapes which is attached to its end. Hence each vibration, each inward thrust, and each outward or backward return of the membrane of the drum, produces by means of the chain of ossicles a corresponding vibration of the membrane of the fenestra ovalis to which the stapes is attached:[1] but the vibrations of this membrane are in turn communicated to the perilymph of the labyrinth and cochlea. Thus by means of the chain of ossicles, and the membranes to which these are attached at each end, the aërial vibrations passing down the meatus are transformed into corresponding vibrations of the fluids of the inner ear. The vibrations of the perilymph passing up the

[1] Owing to certain characters in the attachment of the stapes to the membrane of the fenestra ovalis on the one hand, and to the os orbiculare on the other, the movements of the foot of the stapes in the fenestra ovalis are somewhat peculiar; but the details of these as well as the [illegible] of the peculiar articulation of the incus with the malleus, have for simplicity's sake, been omitted.

estibuli, and down the scala tympani, reach at last
mbrane covering the fenestra rotunda and throw
o vibration ; and as a matter of fact it has been
d that when the membrane of the fenestra ovalis
inward, that of the fenestra rotunda moves out-
and *vice versâ*.

vibrations of the perilymph thus produced will
the endolymph, and this the hairs, and so the
y epithelium of the labyrinth and cochlea ; by
finally, the auditory nerves will be excited.

The Muscles of the Tympanum.—The char-
of the vibration of a membrane, and the readiness
hich it takes up or responds to, aerial vibrations
ng it, are largely modified by its degree of tension ;
embrane acts differently when it is tightly stretched
what it does when it is loose. Now, within the
of the tympanum are two small, but relatively
muscles. One, called the **stapedius**, passes from
or of the tympanum to the foot of the stapes and
bicular bone, the other, the **tensor tympani**, from
nt wall of the drum to the malleus. Each of the
es when it contracts tightens the membrane to which
hus indirectly attached, the tensor tympani, the
rane of the drum, and the stapedius, the membrane
fenestra ovalis. The effect of thus tightening the
rane is probably to restrict the vibrations of the
rane, at least as far as concerns grave, or low-pitched
ls ; but the complete action of these muscles is too
ate to be dwelt on here.

i) **The External Ear.** The outer extremity of the
al meatus is surrounded by the **concha** or external
o. Fig. 123), a broad, peculiarly-shaped, and for
ost part cartilaginous plate, the general plane of
is at right angles with that of the axis of the au-
opening. The concha can be moved by most animals
y some human beings in various directions by means
scles, which pass to it from the side of the head.

(ix) **The Transmission of Sound Waves to the Inner Ear.**—The manner in which the complex apparatus now described intermediates between the physical agent, which is the primary cause of the sensation of sound, and the nervous expansion, the affection of which alone can excite that sensation, must next be considered.

All bodies which produce sound are in a state of vibration, and they communicate the vibrations of their own substance to the air with which they are in contact and thus throw that air into waves, just as a stick waved backwards and forwards in water throws the water into waves.

The aërial waves, produced by the vibrations of sonorous bodies, in part enter the external auditory passage, and in part strike upon the concha of the external ear and the outer surface of the head. It may be that some of the latter impulses are transmitted through the solid structure of the skull to the organ of hearing; but before they reach it they must, under ordinary circumstances, have become so scanty and weak, that they may be left out of consideration.

The aërial waves which enter the meatus all impinge upon the membrane of the drum and set it vibrating, stretched membranes, especially such as have the form and characters of the tympanic membrane, taking up vibrations from the air with great readiness.

The vibrations thus set up in the membrane of the tympanum are communicated, in part, to the air contained in the drum of the ear, and, in part, to the malleus, and thence to the other auditory ossicles.

The vibrations communicated to the air of the drum impinge upon the inner wall of the tympanum, on the greater part of which, from its density, they can produce very little effect. Where this wall is formed by the membrane of the *fenestra rotunda* the communication of motion must necessarily be greater. All these vibrations, however, may probably be neglected.

vibrations which are communicated to the malleus
e chain of ossicles may be of two kinds : vibrations
e particles of the bones, and vibrations of
ones as a whole. If a beam of wood, freely
ded, be very gently scratched with a pin, its
es will be thrown into a state of vibration,
ll be evidenced by the sound given out, but the
itself will not be visibly moved. Again, if a strong
blow against the beam, it will swing bodily, without
ibrations of its particles among themselves. On
her hand, if the beam be sharply struck with a
er, it will not only give out a sound, showing that
rticles are vibrating, but it will also swing, from the
lse given to its whole mass.

der the last-mentioned circumstances, a blind man
ing near the beam would be conscious of nothing
he sound, the product of molecular vibration, or
ble oscillation of the particles of the beam ; while
f man in the same position would be aware of
ng but the visible oscillation of the beam as a
e.

us, to return to the chain of auditory ossicles, while
ay be supposed that, when the membrane of the
vibrates, these may be set vibrating both as a
e and in their particles, the question arises whether
he large vibrations, or the minute ones, which make
selves obvious to the auditory nerve which is in the
ion of our deaf, or blind, man.

e evidence is distinctly in favour of the conclusion,
it is the vibrations of the bones, as a whole, which
ne chief agents in transmitting the impulses of the
waves.

r, in the first place, the disposition of the bones and
node of their articulation are very much against the
mission of molecular vibrations through their sub-
e, but, on the other hand, are extremely favourable
eir vibration *en masse*. The long processes of the

malleus and incus swing, like a pendulum, upon the axis furnished by the short processes of these bones; while the mode of connection of the incus with the stapes, and of the latter with the membrane of the fenestra ovalis, allows the foot-plate of that bone free play, inwards and outwards. In the second place, the total length of the chain of ossicles is very small compared with the length of the waves of audible sounds, and physical considerations teach us that in a like thin rod, similarly capable of swinging *en masse*, the minute molecular vibrations would be inappreciable. Thirdly, direct experiments, such as attaching to the stapes of a dissected ear a light style, the movements of which are recorded on a travelling smoked glass plate or in some other way, show that the chain of ossicles does actually vibrate as a whole, and at the same rate as the membrane of the drum, when aërial vibrations strike upon the latter.

Thus, there is reason to believe that when the tympanic membrane is set vibrating, it causes the process of the malleus, which is fixed to it, to swing at the same rate; the head of the malleus consequently turns through a small arc on its pivot, the slender process. But, as stated on p. 380, the turning of the head of the malleus involves the simultaneous turning of the head of the incus upon its pivot, the short process. In consequence the long process of the incus also swings at the same rate. The length of the long process of the incus, measured from the axis, on which the two bones turn, is less than that of the handle of the malleus; hence the end of it moves through a smaller space. The arc through which it moves has been estimated as being equal to about two-thirds of that described by the handle of the malleus. The extent of the push is thereby somewhat diminished, but the force of the push is proportionately increased; in so confined a space this change is advantageous. The long process of the incus, however, is so fixed to the stapes, and the stapes so attached to the membrane of

nestra ovalis, that the incus cannot vibrate without ing into vibrations, to a corresponding extent and same rate, the membrane of the fenestra ovalis.[1] very vibration, every pull and push, imparts a sponding set of shakes to the perilymph, which fills ony labyrinth and cochlea, external to the mem- us labyrinth and canalis cochlearis. These shakes ommunicated to the endolymph in the latter ers, and, by the help of the modified auditory ilium described above, stimulate the delicate endings vestibular and cochlear divisions of the auditory

The Conversion of Sonorous Vibrations into ations of Sound.—We do not at present know kind of changes the vibrations of the endolymph rise to in the epithelial cells of the maculæ of the ulus and sacculus, of the crests of the ampullæ, and e organ of Corti ; nor do we at present know the way in which the changes thus set up in these elial cells are able to excite the terminal filaments e auditory nerve. But there can be no doubt of act that the elaborate apparatus of the cochlea and mpler apparatus of the labyrinth are able to translate, speak, the sonorous vibrations which reach them stimulations of nerve fibres, the molecular changes hich are transmitted along the auditory nerve as tory nervous impulses. Passing along the auditory e, these molecular changes, these nervous impulses, h certain parts of the brain, situated in the cortex he temporo-sphenoidal lobe, below the fissure of ius (see Lesson XI.), and there in turn set up e molecular disturbances of nervous matter which the immediate cause of the states of feeling d "sounds." Thus the auditory nerve may be , and a similar statement may be made in the of the other nerves of special sensations, to be

[1] See foot-note, p. 380.

provided with two "end-organs." There is the **peripheral end-organ** (the apparatus of the cochlea and labyrinth), by which the physical agent is enabled to excite the sensory nerve-fibres; and there is the **central end-organ,** in the brain, in which the nervous impulses of the sensory nerve excite the special state of feeling which we call the special sensation. The central end-organ of hearing is often spoken of as the auditory sensorium.

Between the sounding body and the actually hearing a sound there is a chain of events of different kinds. There are the vibrations started by the sounding body, and passing through the air, the tympanum, the perilymph, and the endolymph; these are all of one order. Then there are the changes in the peripheral end-organ, in the apparatus of the cochlea and labyrinth; these are of another order. Then follow the molecular disturbances travelling along the auditory nerve: these are of still another order. Lastly, there are the changes in the central end-organ, in the brain; these, though resembling the preceding in so far as they are changes of nervous matter, are yet of still another order, and probably comprise in themselves a whole series of events, the consequence of the last of which is the sensation of sound.

(xi.) **The Respective Functions of the Membranous Labyrinth and the Organ of Corti.**—The differences between the functions of the membranous labyrinth (to which the vestibular nerve is distributed) and those of the cochlea are not quite certainly made out, but the following view has been suggested:—

Every sound consists, as we have seen, of vibrations. Sometimes the vibrations are repeated with great regularity; and sounds, in which the regular recurrence of the same vibrations is conspicuous, are called "musical sounds." Sometimes no regular repetition of vibrations can be recognised; the sound consists of vibrations, few of which are like each other, and which fall irregularly on the ear; such sounds are called "noises."

hen we listen to musical sounds, each set of regularly ed vibrations generates in the central end-organ a cular kind of sensation which we call a *tone*; and the taneous or successive production of different tone- tions gives rise in us to the feelings which we speak those of harmony or melody.

en we listen to a noise the vibrations generate tions which are of a certain intensity, according to we call the noise slight or great, low or loud, and also have certain characters by which we recognise ind of noise; but the sensations have not the quali- f tone-sensations, and do not give rise to feelings of dy or harmony.

d it has been suggested that the arrangements of ochlea are such that musical sounds are enabled to e the cochlear nerve, and to generate in the central rgan connected with it sensations of tone; while rrangements of the labyrinth and the central end- of the vestibular nerve are such as to be readily ed by noises.

ch a view is not without difficulties; but the follow- onsiderations render it probable that the cochlea at is adapted for the appreciation of musical sounds.

pure musical sound consists of a series of vibra- repeated with exact regularity, the number of tions occurring in a given time, *e.g.* in a second, rmining what is called the pitch of the "note." But ıary musical sounds are, for the most part, not simple, ısting of one set of vibrations, but compound, con- ıg of several sets of vibrations occurring together; ese musicians distinguish one set, called the **funda- ıtal tone**, and other sets, varying in intensity or ness, called **overtones**.

tuning-fork, when set vibrating, vibrates with a ı rapidity; and the note given out is determined by apidity of the vibration, by the number of vibrations ated, for instance, in a second; hence every tuning-fork

has its own proper note. Now, a tuning-fork will be set vibrating if its own particular note be sounded in its neighbourhood, but not if other notes be sounded. Hence, when a pure musical note is sounded close to a number of tuning-forks of different pitch, only that tuning-fork the pitch of which is the same as that of the note sounded is set vibrating; the others remain motionless. When an ordinary musical sound, such as a note sung by the human voice, is produced among such a group of tuning-forks, several are set vibrating; one of these corresponds to the fundamental tone, and the others to the various overtones of the sound. Similarly, if the top of a piano be lifted up or removed, and any one sings into the wires with sufficient loudness, a note, such as the tenor c, a number of the wires will be set vibrating, one corresponding to the fundamental tone, and the others to the overtones.

If we were to imagine an immense number of tuning-forks, each vibrating at different periods, so arranged that each fork, when vibrating, in some way or other stimulated or excited a minute delicate nerve-filament attached to it, it is obvious that a musical sound uttered near these tuning-forks would set a certain number of them into vibration, some more forcibly than others, and that in consequence a certain number, and a certain number only, of the delicate nerve-filaments would be excited, and that to various degrees; and thus a particular series of nervous impulses, the counterpart as it were of the musical sound with its fundamental tone and overtones, would be transmitted along the nerve filaments to the brain.

And it is suggested that the basilar membrane of the cochlea, consisting as it does of thousands of fibres stretching across from the inside to the outside (from left to right in Fig. 122), with its thousands of epithelial cells and rods of Corti lying upon it, represents, as it were, an assemblage of thousands of tuning-forks, of various rates of vibration, with a separate nerve filament attached to each. So that, when a number of vibrations of different

ls, such as constitutes an ordinary musical sound, are nitted by the tympanum to the cochlea, these as sweep along the canalis cochlearis throw into sym- tic movement those parts, and those parts only, of silar membrane with their overlying epithelium and f Corti whose periods of vibration correspond to wn vibrations, and thus excite certain nerve fila- , and these only. It is this excitement of a group rve filaments, some more intensely than others, reaching the brain, gives rise to the sensation we associate with the particular musical sound.

has been already stated, we know very little definitely the position in the brain of, and still less about the e of, the auditory sensorium or central end-organ of uditory nerve ; but it may be conceived that each ent of the cochlear nerve is connected with a par- r portion of the nervous matter of the central end- , in such a way that the molecular movements of one ese particular portions of nervous matter, brought by a molecular disturbance reaching it through its priate filament, produces a psychical effect of one only, more or less intense it may be, but still always e kind. If this be so, each cochlear fibre or filament be considered as being provided with two end-organs : peripheral, in the organ of Corti, capable of being set tion by vibrations of one quality only ; the other, al, in the brain, capable of producing a psychical effect e quality only. It does not follow, however, that we distinctly and separately conscious of the nervous dis- ance in each central end-organ, it does not follow we have as many distinct and separate kinds of cious sensation as there are peripheral and central organs, though how many such distinct kinds of ation we may have we do not know. Just as the pheral mechanism sifts out the several vibrations of h a musical sound is composed, and transmits them rately, so, by a reverse operation, the central mech-

anism probably pieces together the nervous disturbances of a number of central end-organs, and thus produces a sensation whose characters are determined by a combination of the nervous disturbances taking place in each end-organ.

Some such a view is indeed exceedingly probable; but it must be remembered that we do not at present at all understand the exact mechanism by which each particular vibration excites its corresponding nerve filament. The nerve filaments appear to end in the epithelial cells bearing short hairs, which lie on each side of the rods of Corti; and we may therefore conclude that these "hair-cells" have some share in producing the effect. But the whole matter is at present very obscure; the functions of the rods of Corti are particularly difficult to understand; for these do not seem in any way connected with the nerve filaments, and their movements can only affect the latter by influencing in some way the hair-cells.

The fibres of the cochlear nerve, or their endings in the brain itself, may be excited by internal causes, such as the varying pressure of the blood and the like: and in some persons such internal influences do give rise to veritable musical spectra, sometimes of a very intense character. But, for the appreciation of music produced external to us, we depend upon the organ of Corti being in some way or other affected by the vibrations of the fluids in the cochlea.

In addition to serving as a portion of the organ of hearing for purely auditory purposes, the semicircular canals play an important part in connection with the maintenance of the equilibrium of the body. But this important function, so wholly different from that of hearing, will be best considered when we come in Lesson XI. to study the actions of the brain.

(xii) **Localisation of Sound.**—The apparatus of the ear which we have described, provides us simply with auditory sensations; enables us to appreciate high notes

low notes, to discriminate between musical sounds noises. Experience then enables us to base upon sensations certain conclusions as to the nature of ource which is giving rise to each sound. The con- ns we thus arrive at are usually more or less accurate. ounds may be coming to us in different directions rom different distances, and when we endeavour to some estimate of either the one or the other of these ple differences we find our means of doing so are very rfect. As to our estimate of the distance from which nd is coming, we are guided chiefly by its varying sity coupled with previous experience and a know- of the laws which connect varying intensity with ifferent distances of the source. For the discrimina- of the direction from which a sound is coming, we have ly almost entirely on the different effect the sound uces on each of our two ears, according as it falls directly into one of them than into the other. Thus we are endeavouring to localise a source of sound, sually turn the head into various positions until we find position in which the sound is loudest as it falls into ear, and then we assume that the sound is coming a line directed straight into that ear. In animals large and movable external ears, the movement of ar to a great extent takes the place of the movement ne head; this may be readily observed in an animal as the horse.

nything which interferes with the ordinary laws of sference of sound causes us to form a wrong judgment the distance of the source, as in the case of listening speech through a telephone or in a phonograph. ilarly, it is difficult to estimate the distance of the ce of a sound heard through a snow storm. Again, entriloquism our judgment is upset, not only as rds the nature of the source of sound, but also of its ance and direction, by carefully planned simulation suggestion.

(xiii) **The Functions of the Tympanic Muscles and Eustachian Tube.**—It has already been explained that the *stapedius* and *tensor tympani* muscles are competent to tighten the membrane of the fenestra ovalis and that of the tympanum, and it is probable that they come into action when the sonorous impulses are too violent, and would produce too extensive vibrations of these membranes. They may therefore be of use in moderating the effect of intense sound, in much the same way that, as we shall find, the contraction of the circular fibres of the iris tends to moderate the effect of intense light in the eye; they may, however, have other purposes.

The function of the Eustachian tube is, probably, to keep the air in the tympanum, or on the inner side of the tympanic membrane, of about the same tension as that on the outer side, which could not always be the case if the tympanum were a closed cavity. The unpleasant sensation often experienced, as of a "tightness" in the ear, when diving under water, is due to the compression of the air in the tympanic cavity under the increased external pressure. It may be largely removed by merely performing the movements of swallowing. By these movements the end of the Eustachian tube which opens into the pharynx is opened and the pressure on the two sides of the tympanum is equalised.

LESSON IX

THE ORGAN OF SIGHT

The General Structure of the Eye.—Every sense-
consists of two parts ; the *essential part*, consisting
structures in which the sensory nerve supplied to
rgan terminate, and in which the impulses which
up that nerve are generated, and the *accessory part*,
ged so as to bring the agent, which affects the organ,
ar upon the essential part. In the case of the sense-
ns so far described, we dealt first, with the essential
and then with the accessory arrangements. But in
ase of the eye, the accessory structures are so com-
ted and their action so striking that they seem, at
sight, to form the greater part of the whole sense-
n. Hence we may, perhaps with advantage, consider
ccessory parts first, and then pass on to the essential
tures.

e accessory organs, by means of which the physical
t of vision, light, is enabled to act upon the expan-
of the optic nerve, comprise three kinds of appar-
: (*a*) a "water camera," the eyeball ; (*b*) muscles
moving the eyeball ; (*c*) organs for protecting the
ll, viz. the eyelids, with their lashes, glands, and
les ; the conjunctiva ; and the lachrymal gland and
ucts.

e ball, or globe, of the eye is a globular body, moving
y in a chamber, the **orbit**, which is furnished to it
e skull. The optic nerve, the root of which is in

the brain, leaves the skull by a hole at the back of the orbit, and enters the back of the globe of the eye, not in the middle, but on the inner, or nasal, side of the centre. Having pierced the wall of the globe, it spreads out into a very delicate membrane, varying in thickness from $\frac{1}{80}$th of an inch to less than half that amount, which lines the hinder two-thirds of the globe, and is termed the **retina**. This retina is the only organ connected with sensory nervous fibres which can be affected, by any agent, in such a manner as to give rise to the sensation of light.

The **eyeball** is composed, in the first place, of a tough, firm, spheroidal case consisting of fibrous or connective tissue, the greater part of which is white and opaque, and is called the **sclerotic** (Fig. 126, 2). In front, however, this fibrous capsule of the eye, though it does not change its essential character, becomes transparent, and receives the name of the **cornea** (Fig. 126, 1). The front surface of the cornea is covered by an epithelium in which the cells are very similar and similarly arranged to those in the epidermis of the skin. The corneal portion of the case of the eyeball is more convex than the sclerotic portion, so that the whole form of the ball is such as would be produced by cutting off a segment from the front of a spheroid of the diameter of the sclerotic, and replacing this by a segment cut from a smaller, and consequently more convex, spheroid.

The corneo-sclerotic case of the eye is kept in shape by what are termed the *humours*—watery or semi-fluid substances, one of which, the **aqueous humour** (Fig. 126, 7), which is hardly more than water holding a few organic and saline substances in solution, distends the corneal chamber of the eye, while the other, the **vitreous humour** (Fig. 126, 13), which is rather a delicate jelly than a regular fluid, keeps the sclerotic chamber full.

The two humours are separated by the very beautiful, transparent doubly-convex **crystalline lens** (Fig. 126, 12),

er, and capable of refracting light more strongly either of the humours. The crystalline lens is com- of fibres having a somewhat complex arrangement,

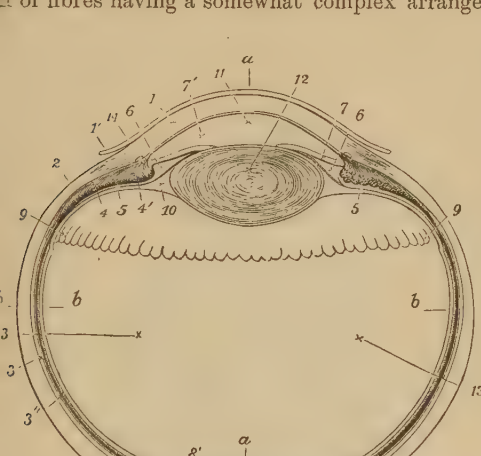


Fig. 126.—Horizontal Section of the Eyeball.

rnea; 1′, conjunctiva; 2, sclerotic; 2′, sheath of optic nerve; oid; 3″, rods and cones of the retina; 4, ciliary muscle; 4′, cir- ortion of ciliary muscle; 5, ciliary process; 6, posterior chamber n; 7, the iris and the suspensory ligament; 7′, anterior chamber; y of retina in the centre of the optic nerve; 8′, centre of blind 8″, macula lutea; 9, ora serrata (this is of course not seen in a such as this, but is introduced to show its position); 10, space the suspensory ligament (canal of Petit); 12, crystalline lens; reous humour; 14, marks the position of the ciliary ligament; tic axis; *b b*, line of equator of the eyeball.

highly elastic. It is more convex behind than in and it is kept in place by a delicate, but at the

same time strong membranous frame or **suspensory ligament**, which extends from the edges of the lens to what are termed the **ciliary processes** of the choroid coat (Figs. 126, 5, and 128, *c*). In the ordinary condition of the eye this ligament is kept tense, *i.e.* is stretched pretty tight, and the front part of the lens is consequently flattened.

The **choroid coat** is highly vascular and consists of blood-vessels arranged in a very complex way, bound together with a little connective tissue among which, towards its inner side, are a number of branched connec-

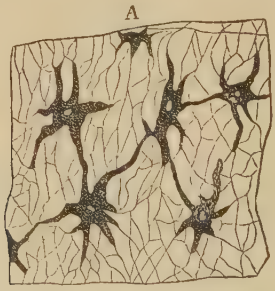


FIG. 127.—PIGMENT CELLS FROM THE CHOROID COAT.

tive tissue corpuscles whose cell-substance is loaded with granules of **black pigment** (Fig. 127).

The choroid is in close contact with the sclerotic externally, and internally is in contact with a layer of very peculiar cells, also full of pigment (Fig. 139). But these cells really belong to the retina and will therefore be described later on (p. 419). They are separated from the vitreous humour by the retina only. The choroid lines every part of the sclerotic, except just where the optic nerve enters it at a point below, and to the inner side of the centre of the back of the eye; but when it reaches

front part of the sclerotic, its inner surface becomes ed up into a number of longitudinal ridges, with rvening depressions, like the crimped frills of a lady's s, terminating within and in front by rounded ends, passing, externally, into the iris. These ridges, h when viewed from behind seem to radiate on all from the lens (Figs. 128, *c*, and 126, 5), are the e-mentioned ciliary processes.

he **iris** itself (Figs. 126, 7, and 128, *a*, *b*) is, as has already said (p. 301), a curtain with a round hole in middle, the **pupil**, provided with circular and radiating riped muscular fibres, and capable of having its ral aperture enlarged or diminished by the action of e fibres, the contraction of which, unlike that of r unstriped muscular fibres, is extremely rapid. The es of the iris are firmly connected with the capsule of eye, at the junction of the cornea and sclerotic, by connective tissue which enters into the composition hat used to be called the **ciliary ligament.** The ler surface of the iris is covered with cells containing ack pigment, similar to that of the choroid coat, and different colours of eyes depend partly on the varying unt and distribution of pigment in these cells, but fly on pigment cells imbedded in and scattered ughout the substance of the iris. Unstriped muscular es, having the same attachment in front, spread back- ds on to the outer surface of the choroid, constituting **ciliary muscle** (Fig. 126, 4). If these fibres ract, it is obvious that they will pull the choroid ards ; and as the frame, or suspensory ligament of lens, is connected with the ciliary processes (which ly form the anterior termination of the choroid), pulling forward of the choroid comes to the same as a relaxation of the tension of that suspensory ment, which, as we have just said, is in an ordinary ition stretched somewhat tight, keeping the front of ens flattened.

The iris does not hang down perpendicularly into the space between the front face of the crystalline lens and the posterior surface of the cornea, which is filled by the aqueous humour, but applies itself very closely to the anterior face of the lens, so that hardly any interval is left between the two (Figs. 126 and 131).

The retina lines the interior of the eye, being placed between the choroid and vitreous humour, its rods and cones being imbedded in the pigment epithelium lining

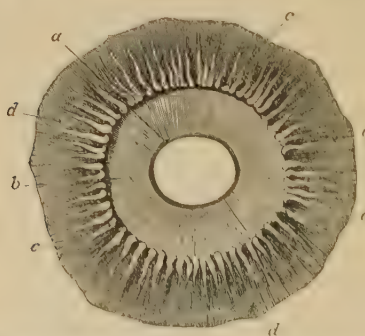


Fig. 128.—View of Front Half of the Eyeball seen from behind.

a, circular fibres; *b*, radiating fibres of the iris; *c*, ciliary processes; *d*, choroid. The crystalline lens has been removed.

the former, and its inner limiting membrane touching the latter.

About a third of the distance back from the front of the eye the retina seems to end in a wavy border called the **ora serrata** (Fig. 126, 9), and in reality the nervous elements of the retina do end here, having become considerably reduced before this line is reached. Some of the connective tissue elements however pass on as a delicate kind of membrane at the back of the ciliary processes towards the crystalline lens.

The Eye as a Water-Camera.—The impact of the eal vibrations upon the sensory expansion, or *essential* f the visual apparatus alone, is sufficient to give rise those *feelings*, which we term sensations of *light* and *lour*, and further to that feeling of *outness* which panies all visual sensation. But, if the retina had ple transparent covering, the vibrations radiating any number of distinct luminous points in the nal world would affect all parts of it equally, and fore the feeling aroused would be that of a generally ed luminosity. There would be no separate feeling ght for each separate radiating point, and hence no spondence between the visual sensations and the ting points which aroused them.

is obvious that, in order to produce this correspond- , or, in other words, to have distinct vision, the ntial condition is, that distinct luminous points in the rnal world shall be represented by distinct feelings of . And since, in order to produce these distinct ngs, vibrations must fall on separate parts of the a, it follows that, for the production of distinct n, some apparatus must be interposed between the na and the external world, by the action of which inct luminous points in the latter shall be represented orresponding points of light on the retina.

the eye of man and of the higher animals, this *acces-* apparatus of vision is represented by structures which, n together, act as a biconvex lens, composed of sub- ces which have a much greater refractive power than air by which the eye is surrounded ; and which throw n the retina luminous points, which correspond in nber, and in position relatively to one another, with se luminous points in the external world from which ereal vibrations proceed towards the eye. The lumin- points thus thrown upon the retina form a picture he external world—a picture being nothing but lights shadows, or colours, arranged in such a way as to

correspond with the disposition of the luminous parts o the object represented, and with the qualities of the ligh which proceeds from them.

That a biconvex lens is competent to produce a pictur of the external world on a properly arranged screen is fact of which every one can assure himself by simpl experiments. An ordinary magnifying glass is a trans parent body denser than the air, and convex on both sides. If this **lens** be held at a certain distance from a screen or wall in a dark room, and a lighted candle b placed on the opposite side of it, it will be easy to adjus the distances of candle, lens, and wall, in such a manne that an image of the flame of the candle, upside down shall be thrown upon the wall.

The spot on which the image is formed is called a **focus**. If the candle be now brought nearer to the lens, the image on the wall will enlarge, and grow blurred and dim, but it may be restored to brightness and definition by moving the lens further from the wall. But if, when the new adjustment has taken place, the candle be moved away from the lens, the image will again become confused, and to restore its clearness, the lens will have to be brought nearer the wall.

Thus a convex lens forms a distinct picture of luminous objects, but only at the focus on the side of the lens opposite to the object; and that focus is nearer when the object is distant, and further off when it is near.

Suppose, however, that, leaving the candle unmoved, a lens with more convex surfaces is substituted for the first, the image will be blurred, and the lens will have to be moved nearer the wall to give it definition. If, on the other hand, a lens with less convex surfaces is substituted for the first, it must be moved further from the wall to attain the same end.

In other words, other things being alike, the more convex the lens the nearer its focus; the less convex, the further off its focus.

he lens were made of some extensible, elastic sub-
, like india-rubber, pulling it at the circumference
render it flatter, and thereby lengthen its focus;
when let go again, it would become more convex,
shorter focus.

material more refractive than the medium in which
laced, if it have a convex surface, causes the rays of
which pass through the less refractive medium to
urface to converge towards a focus. If a watch-glass
ed into one side of a box, and the box be then filled
water, a candle may be placed at such a distance
e the watch-glass that an image of its flame shall
the opposite wall of the box. If, under these cir-
ances, a doubly convex lens of glass were introduced
he water in the path of the rays, it would act (though
owerfully than if it were in air) in bringing the rays
quickly to a focus, because glass refracts light more
gly than water does.

amera obscura is a box, into one side of which a lens
ed, so as to be able to slide backwards and forwards,
hus throw on the screen at the back of the box dis-
images of bodies at various distances off. Hence
rangement just described might be termed a *water*
a.

e eyeball, the most important constituents of which
now been described, is, in principle, a camera of the
described above—a water camera. That is to say,
clerotic answers to the box, the cornea to the watch-
, the aqueous and vitreous humours to the water
g the box, the crystalline to the glass lens, the
duction of which was imagined. The back of the
corresponds with the retina.

at further, in an ordinary camera obscura, it is found
able to have what is termed a **diaphragm** (that is,
paque plate with a hole in its centre) in the
of the rays, for the purpose of moderating the light
cutting off the marginal rays which, owing to certain

optical properties of spheroidal surfaces, give rise t defects in the image formed at the focus.

In the eye, the place of this diaphragm is taken by th **iris**, which has the peculiar advantage of being self-regu lating : contracting its aperture and admitting less ligh when the illumination is strong ; but dilating its apertu and admitting more light when the light is weak. T thus acts like the various "stops" which a photographe uses according to the varying light.

These changes in the pupil are brought about by th contractions of the circular and radiating muscle-fibres o the iris ; contraction of the circular or sphincter fibre makes the pupil smaller or constricts it, contraction o the radiating fibres makes it larger or dilates it. Furthe conversely relaxation of the circular fibres causes or help to cause dilation, and relaxation of the radiating fibre causes or helps to cause constriction. Contraction of th circular fibres and so *constriction* of the pupil is brough about by means of fibres of the *oculo-motor* nerve, an contraction of the radiating fibres and so *active dilation* i brought about by means of fibres of the *sympathet* system and may be induced by stimulation of the sym pathetic in the neck.

The constriction of the pupil observed when light fal upon the retina is a reflex action in which the optic nerv provides the path for afferent impulses to a centre in th brain lying beneath the front end of the aqueduct Sylvius (see Lesson XI), and the third (oculo-moto cranial nerve (see Lesson XI) provides the path fo efferent impulses from the centre to the circular fibres the iris. The dilation of the pupil when light is with drawn from the retina is in the main at least due to th cessation of previously acting constrictor impulses.

But the pupil, or aperture of the iris, is either co stricted or dilated under many circumstances, other tha the mere action of light and darkness on the retin Thus it is *constricted* when the eye is accommodated f

objects, during deep sleep, or after the administration
rphia and several other poisons, and in the early
of the action of alcohol and chloroform. On the
hand the pupil is *dilated* when the eye is accommo-
for distant objects, during violent muscular activity,
dyspnœa, after the administration of atropine
ne other poisons, and in the later stages of the
of alcohol and chloroform.

the case of the action of many poisons the effect
ced is due, notably in respect of atropine, to a purely
ction on the circular (sphincter) fibres of the iris.

ys of light passing into the eye undergo a bending or
tion (i) as they enter the eye, at the surface of the
a, (ii) as they pass through the lens; and as a

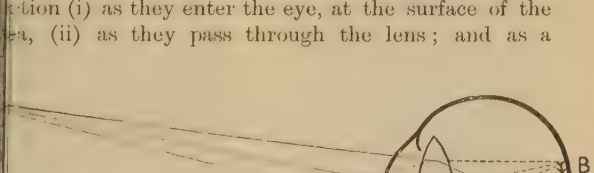


Fig. 129.– The Formation of an Image on the Retina.

t of this action of the cornea and lens an image of
object in the external world is formed on the retina.
the water camera the image brought to a focus on
creen at the back is *inverted*; the image of a tree for
nce is seen with the roots upwards and the leaves and
ches hanging downwards. The right of the image
corresponds with the left of the object and *vice versâ*.
tly the same thing takes place in the eye with the
e focussed on the retina. It too is inverted. This
often gives rise to the question, Why then do we see
cts in the external world in an erect position and not

also inverted? The answer is simple, and is given in Lesson X.

3. **The Mechanism of Accommodation.** - In the water camera, constructed according to the description given above, there is the defect that no provision exists for adjusting the focus to the varying distances of objects. If the box were so made that its back, on which the image is supposed to be thrown, received distinct images of very distant objects, all near ones would be indistinct. And if, on the other hand, it were fitted to receive the image of near objects, at a given distance, those of either still nearer, or more distant, bodies would be blurred and indistinct. In the ordinary camera this difficulty is overcome by sliding the lenses in and out, a process which is not compatible with the construction of our water camera. But there is clearly one way among many in which this adjustment might be effected - namely, by changing the glass lens; putting in a less convex one when more distant objects had to be pictured, and a more convex one when the images of nearer objects were to be thrown upon the back of the box.

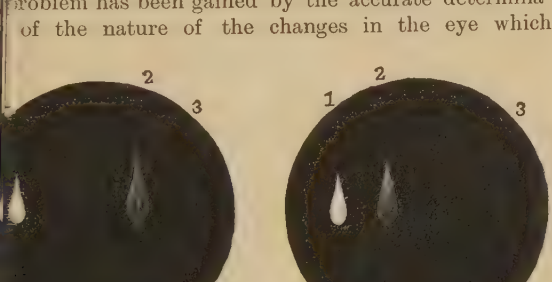
But it would come to the same thing, and be much more convenient, if, without changing the lens, one and the same lens could be made to alter its convexity. This is what actually is done in the adjustment of the eye to distances.

The simplest way of experimenting on the *adjustment* or **accommodation of the eye** is to stick two stout needles upright into a straight piece of wood, not exactly but nearly in the same straight line, so that, on applying the eye to one end of the piece of wood, one needle (*a*) shall be seen about six inches off, and the other (*b*) just on one side of it at twelve inches or more distance.

If the observer look at the needle *b*, he will find that he sees it very distinctly, and without the least sense of effort; but the image of *a* is blurred and more or less double. Now let him try to make this blurred image

needle *a* distinct. He will find he can do so readily gh, but that the act is accompanied by a sense of somewhere in the eye. And in proportion as *a* nes distinct, *b* will become blurred. Nor will any enable him to see *a* and *b* distinctly at the same

ultitudes of explanations have been given of this rkable power of adjustment; but the true solution of problem has been gained by the accurate determina- of the nature of the changes in the eye which



130.—Diagram of the Images of a Candle-Flame seen by Reflection from the Surface of the Cornea and the two Surfaces of the Lens.

A, as seen when the eye is adjusted for a distant object; *B*, as they appear when the eye is fixed on a near object.

ompany the act. When the flame of a taper is held r, and a little on one side of, a person's eye, any one king into the eye from a proper point of view will three images of the flame, two upright and one in- ted. One upright bright image is reflected from the nt of the cornea, which acts as a convex mirror. The ond, less bright, proceeds from the front of the stalline lens, which has the same effect; while the erted image, which is small and indistinct, proceeds

from the posterior face of the lens, which, being convex backwards, is, of course, concave forwards, and acts as a concave mirror (Fig. 130, *A*).

Suppose the eye to be steadily fixed on a distant object, and then adjusted to a near one in the same line of vision, the position of the eyeball remaining unchanged. Then the upright image reflected from the surface of the cornea, and the inverted image from the back of the lens, will remain unchanged, though it is demonstrable that their size or apparent position must change if either the cornea or the back of the lens, alter either their form or their

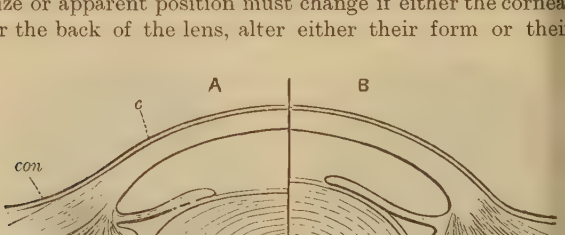


FIG. 131.—THE CHANGES IN THE LENS IN ACCOMMODATION.

A, adjusted for distant; B, for near objects.
c, cornea; *con.* conjunctiva; *scl.* sclerotic; *ch.* choroid; *c.p*, ciliary process; *c.m*, ciliary muscle; *s.l*, suspensory ligament.

position. But the second upright image, that reflected by the front face of the lens, does change both its size and its position; it comes forward and grows smaller (Fig. 130, *B*), proving that the front face of the lens has become more convex. The change of form of the lens is, in fact, that represented in Fig. 131.

For purposes of accurate experiment it is better to employ the images cast by *two* small luminous points placed one above the other. In this case *three pairs* of images are seen by reflection; and it is easier to observe

he *two* images of the middle pair come nearer to-
r when the eye is accommodated for a near object
it is to observe the slight movement and diminution
e of the *single image* of a candle flame.

ese may be regarded as the *facts of adjustment* with
all explanations of that process must accord. They
e exclude the hypothesis (1) that adjustment is the
of the compression of the ball of the eye by its
les, which would cause a change in the form of the
a ; (2) that adjustment results from a shifting of the
bodily, for its hinder face does not move ; (3) that it
ts from the pressure of the iris upon the front face of
ens, for under these circumstances the hinder face of
lens would not remain stationary. This last hypo-
is is further negatived by the fact that adjustment
s place equally well when the iris is absent.

ut one other explanation remains, which is not only
edingly probable from the anatomical relations of the
s, but is also supported by direct experimental evi-
e. The lens, which is very elastic, is kept habitually
state of compression by the pressure exerted on it by
suspensory ligament, and consequently has a flatter
than it would take if left to itself. If the ciliary
cle contracts, it must, as has been seen, relax that
ment, and thereby diminish its pressure upon the lens.
lens, consequently, will become more convex ; it will,
ever, since it is highly elastic, return to its former
e when the ciliary muscle ceases to contract, and
s the choroid to return to its ordinary place.

ence probably the sense of effort we feel when we
st for near distances arises from the contraction of
iliary muscle.

The Limits of Accommodation. Use of Spectacles. djustment can take place only within a certain e ; this, however, admits of great individual varia-s.

eople possessing ordinary, or as it is called "normal"

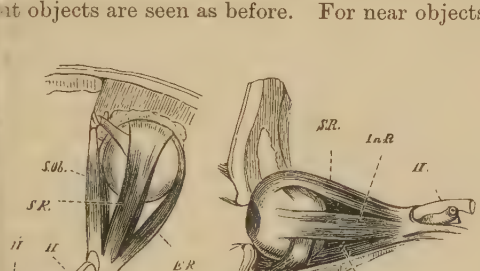
sight can adjust their eyes so as to see distinctly object as near to the eye as five or six inches ; but the image o an object brought nearer than this becomes blurred and indistinct, because the "near limit" of adjustment is the passed. They can also adjust their eyes for objects at very great distance, the indistinctness of the images o objects very far off being due, not to want of proper focus sing, but to the details being lost through the minutenes of the image.

Some people, however, are born with, or at least come to possess, eyes in which the "near limit" of adjust ment is much closer. Such persons can see distinctly ob jects as near to the cornea as even one or two inches but they cannot adjust their eyes to objects at any grea distance off. Thus many of these "near-sighted" people as they are called, cannot see distinctly the features of person only a few feet off. Though their ciliary muscl remains quite relaxed so that the suspensory ligamen keeps the lens as flat as possible, the arrangements of th eye are such that the image of an object only a few fee off is brought to a focus in front of the retina, somewhere i the vitreous humour. By wearing **concave** glasses thes near-sighted people are able to bring the image of distan objects on to the retina and thus to see them distinctly.

The cause of near-sightedness is not always the same but in the majority of cases it appears to be due to th bulb of the eye being unusually long from back to fron If, in the water-camera described above, when the len and object were so adjusted that the image of the objec was distinctly focussed on the screen, the box were mad longer, so that the screen was moved backwards, th distinctness of the image on it would be lost.

Some people are born really "long-sighted," inasmuc as they can see distinctly only such objects as are qui distant ; and indeed have to contract their ciliary muscle and so make their lens more convex even to see thes Near objects they cannot see distinctly at all unless the

convex glasses. In such persons the bulb of the
s generally too short.
ind of long-sightedness also comes on in old people ;
his is different from the above, and is simply due, in
ajority of cases at all events, to a loss of power of
ment. The refractive power of the eye remains the
but the ciliary muscle fails to work ; and hence ad-
ent for near objects becomes impossible, though
t objects are seen as before. For near objects such



A FIG. 132. B

he muscles of the right eyeball viewed from above, and B of the yeball viewed from the outer side ; *S.R*, the superior rectus ; *Inf.R*, nferior rectus ; *E.R*, *In.R*, the external rectus ; *S.Ob.* the superior ıe ; *Inf.Ob.* the inferior oblique ; *Ch.* the chiasma of the optic s (*II.*) ; *III*, the third nerve which supplies all the muscles except ıperior oblique and the external rectus.

ons have to use **convex** glasses. They should per-
be called " old-sighted " rather than " long-sighted."

The Muscles of the Eyeball.—The *muscles* which
e the eyeball are altogether six in number—four
ght muscles, or **recti**, and two oblique muscles, the
qui (Fig. 132). The straight muscles are attached to
ack of the bony orbit, round the edges of the hole
ugh which the optic nerve passes, and run straight

forward to their insertions into the sclerotic—one, the **superior rectus**, in the middle line above; one, the **inferior**, opposite it below; and one half-way on each side, the **external** and **internal recti**. The eyeball is completely imbedded in fat behind and laterally; and these muscles turn it as on a cushion; the superior rectus inclining the axis of the eye upwards, the inferior downwards, the external outwards, the internal inwards.

The two oblique muscles, upper and lower, are both attached on the outer side of the ball, and rather behind its centre; and they both pull in a direction from the point of attachment towards the inner side of the orbit—the lower, because it arises here; the upper, because, though it arises along with the *recti* from the back of the orbit, yet, after passing forwards and becoming tendinous at the upper and inner corner of the orbit, it traverses a pulley-like loop of ligament, and then turns downwards and outwards to its insertion. The action of the oblique muscles is somewhat complicated, but their general tendency is to roll the eyeball on its axis, and pull it a little forward and inward.

By means of the contraction of these several muscles the eyeballs may be moved into any desired position and their optic axes (Fig. 126, *a.a.*) directed straight towards any object. This mobility is largely of use in diminishing the necessity for such frequent movements of the whole head as would otherwise be necessary. But the movements are also chiefly of extreme importance as ensuring that any object is seen as *single*, although there is an image of it on the retina of each of the *two eyes*.

6. The Protective Appendages of the Eye.—The **eyelids** are folds of skin containing thin plates of cartilage, and fringed at the edges with hairs, the **eyelashes**, and with a series of small glands called **Meibomian**. Circularly disposed fibres of striped muscle lie beneath the integuments of the eyelids, and constitute the **orbicularis** muscle which shuts them. The upper eyelid is

by a special muscle, the **levator** of the upper lid arises at the back of the orbit and runs forwards to the lid.

lower lid has no special depressor.

the edge of the eyelids the integument becomes uous with a delicate, vascular and highly nervous s membrane, the **conjunctiva,** which lines the in- of the lids and the front of the eyeball, its epithelial being even continued over the cornea. The nume- small ducts of a which is lodged in rbit, on the outer f the ball (Fig. 133, , the **lachrymal** d, constantly pour atery secretion into interspace between njunctiva lining the eyelid and that ng the ball. On inner side of the is a reddish fold, **aruncula lachry-s,** a sort of rudi- of that third eye- hich is to be found ny animals. Above below, close to the cula, the edge of each eyelid presents a minute ure (the *punctum lachrymale*), the opening of a small

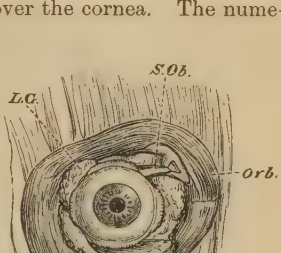


FIG. 133.

The front view of the right eye dissected to show *Orb.* the orbicular muscle of the eyelids; the pulley and insertion of the superior oblique, *S.Ob.*, and the inferior oblique, *Inf.Ob.*; *L.G*, the lachrymal gland.

The canals from above and below converge and into the **lachrymal sac**; the upper blind end of (*L.D.*, Fig. 134) which passes down from the orbit e nose, opening below the inferior turbinal bone 69, *h*). It is through this system of canals that the nctival mucous membrane is continuous with that e nose; and it is by them that the secretion of the

lachrymal gland is ordinarily carried away as fast as i forms.

But, under certain circumstances, as when the con junctiva is irritated by pungent vapours, or when painfu emotions arise in the mind, the secretion of the lachryma gland exceeds the drainage power of the lachrymal duct and the fluid, accumulating between the lids, at length overflows in the form of tears.

7. The Structure of the Retina.—If the globe of the eye be cut in two, transversely, so as to divide it into an anterior and a posterior half, the retina will be seen lining the whole of the concave wall of the posterior half as a membrane of great delicacy, and, for the most part, of even texture and smooth surface. But almost exactly opposite the middle of the posterior wall, it presents a slight circular depression of a yellowish hue, the **macula lutea**, or yellow spot (Fig. 135, *m.l.*; Fig. 126, 8″),—not easily seen, however, unless the eye be perfectly fresh,—and, at some distance from this, towards the inner or nasal, side of the ball, is a radiating appearance, produced by the entrance of the optic nerve and the spreading out of its fibres into the retina.

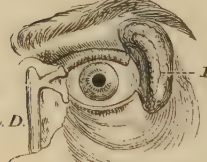


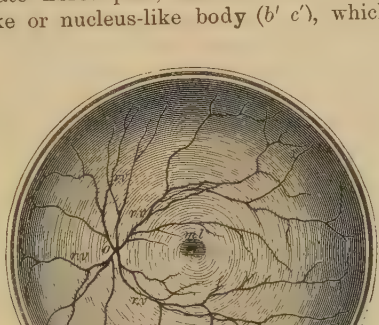
FIG. 134.

A front view of the left eye, with the eyelids partially dissected to show lachrymal gland, *L.G*, and lachrymal duct, *L.D.*

A very thin vertical slice of the retina, in any region except the yellow spot and the entrance of the optic nerve, may be resolved into the structures represented separately in Fig. 136. The one of these (A) occupies the whole thickness of the section, and comprises its essential, or nervous, elements. The outer[1] fourth, o

[1] In the following account of the retina, the parts are described in relation to the eyeball. Thus, that surface of the retina which touches th

r less, of the thickness of these consists of a vast itude of minute, either rod-like, or conical bodies, d side by side, perpendicularly to the plane of the a. This is the **layer of rods and cones** (*b c*). the front ends or bases of the rods and cones delicate fibres pass, and in each is developed a le-like or nucleus-like body (*b' c'*), which forms a



135.—THE EYEBALL DIVIDED TRANSVERSELY IN THE MIDDLE LINE AND VIEWED FROM THE FRONT.

sclerotic; *ch*, choroid, seen in section only.
the cut edges of the retina; *r.v*, vessels of the retina springing n *o*, the optic nerve or blind spot; *m.l*, the yellow spot, the darker , in its middle being the fovea centralis.

t of what has been termed the **outer nuclear layer.** is probable that these fibres next pass into and indeed m the close meshwork of very delicate nervous fibres,

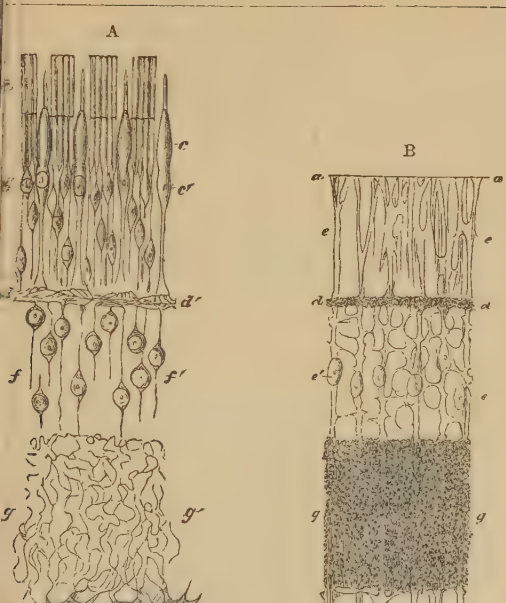
reous humour, and so is nearer the centre of the eyeball, is called the *ner* surface; and that surface which touches the choroid coat is called *e outer* surface. And so with the structures between these two sur- es; that which is called inner is nearer the vitreous humour, and that ich is called outer is nearer the choroid coat. Sometimes *anterior*, or nt, is used instead of inner, and *posterior* instead of outer.

the **outer molecular layer**, which is seen at *d d'* (Fig 136, A). From the inner surface of this meshwork othe fibres proceed, containing a second set of granules o nuclei, which forms the **inner nuclear layer** (*f f*) Inside this layer is a stratum of convoluted fine nervou fibres, the **inner molecular layer** (*g g'*)—and insid this again are numerous **nerve-cells** (*h h'*) constitutin the **layer of ganglionic cells.** Processes of thes nerve-cells extend, on the one hand, into the layer o convoluted nerve-fibres ; and on the other are continuou with the stratum of **fibres of the optic nerve** (*i*).

These delicate nervous structures are supported by sort of framework of connective tissue of a peculiar kin (B), which extends from an **inner** or **anterior limitin membrane** (*l*), which bounds the retina and is in con tact with the vitreous humour, to an **outer** or **posterio limiting membrane**, which lies at the inner ends, o bases, of the rods and cones near the level of *b' c'* in A Thus the framework falls short of the nervous substanc of the retina, and the rods and cones lie altogether outsid of it, wholly unsupported by any connective tissue. The are, however, as we shall see, imbedded in the layer o pigment on which the retina rests (p. 419).

The fibres of the optic nerve spread out between th inner limiting membrane (*l*) and the nerve-cells (*h'*), and th vessels which enter along with the optic nerve, consistin of an artery which pierces the centre of the nerve (Fig 135), ramify between the two limiting membranes, mos of them running between the inner limiting membran and the inner nuclear layer (*f f'*). Thus, not only th nervous fibres, but the vessels, are placed altogether i front of the rods and cones.

The structural appearance of the nervous elements o the retina and the seven "layers" into which it may b divided as described above is such as can be made out i any ordinarily stained section. Such a section tells us ver little, except in the case of the rods and cones, as to th



136.—Diagrammatic Views of the Nervous (A) and the Connective (B) Elements of the Retina, supposed to be separated from one another.

The nervous structures—*b*, the rods; *c*, the cones; *b'.c'*, the granules of the outer layer, with which these are connected; *d.d'*, inter- a very delicate nervous fibres, from which fine nervous filaments, ing the inner granules or nuclei, *f,f'*, proceed towards the inner sur- *g.g'*, the continuation of these fine nerves, which become convo- and interwoven with the processes of the nerve cells *h.h'*; *i.i*, the ision of the fibres of the optic nerve. B, the connective tissue— xternal limiting membrane; *e.e*, radial fibres passing to the internal ng membrane; *e'.e'*, nuclei; *d.d*, the intergranular layer; *g.g*, the ular layer; *l*, the inner limiting membrane.

(Magnified about 250 diameters.)

real nature of the several structures which give to each layer its characteristic appearance. Still less does it give any clue to the nature of the connections of the successive

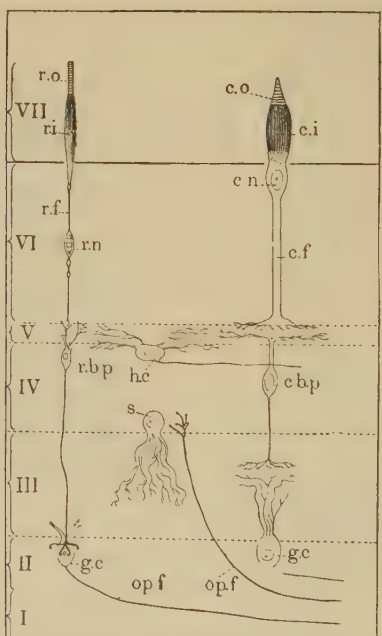


FIG. 137.—DIAGRAM IN ILLUSTRATION OF THE NERVOUS STRUCTURE OF THE RETINA.

I—VII, the several "layers" of the retina.
r.o, *r.i*, outer and inner limbs of a rod; *r.f*, rod fibre; *r.n*, rod nucleus; *c.b.p*, rod bipolar cell; *c.o*, *c.i*, outer and inner limbs of a cone; *c.f*, cone fibre; *c.n*, cone nucleus; *c.b.p*, cone bipolar cell; *g.c*, *g.c*, two cells of the ganglionic cell layer; *op.f*, *op.f*, fibres of optic nerve.

layers with each other by which the *functional continuity* of the rods and cones with the fibres of the optic nerve is brought about. But by the application of very special

ods of staining many details have recently been out which seem to justify the construction of the ving diagrammatic figure (Fig. 137) in illustration of tructure of the retina and of the relationships of its al layers. In this figure the facts of chief and diate interest are those which refer to the mode of ction between a rod on the one hand and a cone on her with the fibre of the optic nerve.

the case of a rod the rod-fibre (*r.f.*) is seen to end e outer molecular layer (*V*) as an extremely minute . This knob is *surrounded by* processes from the end of a *rod bipolar cell* (*r.b.p.*) whose body lies in nner nuclear layer (*IV*).

e inner end of this cell ends in branching processes t *surround* the body of one of the cells in the lionic-cell layer (*II*), which is itself in direct continuity a fibre of the optic nerve (*op.f.*).

the case of a cone the cone-fibre (*c.f.*) ends as a ned expansion, from which fine processes extend, in uter molecular layer (*V*). Immediately below these sses of the base of a cone-fibre, but not actually inuous with them, lie the processes from the outer of a *cone bipolar cell* (*c.b.p.*) whose body is again ted in the inner nuclear layer (*IV*). The inner end his cell terminates in expanded branches in the r molecular layer (*III*). Facing these, but not in al continuity with them, lie the processes from the r end of one of the cells in the ganglionic-cell layer which, as before, is itself directly connected with a of the optic nerve.

this way each rod and cone is brought into relation- with a fibre of the optic nerve; but the path of ection in each case shows *two breaks in its structural nuity.* In the case of a rod these breaks lie in the r molecular layer (*V*) and ganglionic layer (*II*); in the of a cone they lie in the outer and inner molecular s respectively (*V* and *III*).

FIG. 138.—A DIAGRAMMATIC SECTION OF THE MACULA LUTEA, OR YELLOW SPOT.

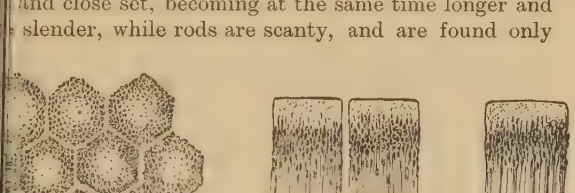
a.a, the pigment of the choroid; *b.c*, rods and cones; *d.d*, outer granular or nuclear layer; *f.f*, inner granular or nuclear layer; *g.g*, molecular layer; *h.h*, layer of nerve cells; *i.i*, fibres of the optic nerve.

(Magnified about 60 diameters.)

In addition to the bipolar cells (*r.b.p.* and *c.b.p.*) which chiefly confer upon the inner nuclear layer (*IV*) the

cteristic appearance from which it derives its name, cells also occur in this layer. These are shown at *h.c.* ; but their relationships to the other structural nts of the retina are so uncertain that we must ut ourselves with merely drawing attention to their nce.

the entrance of the optic nerve itself, the nervous predominate, and the rods and cones are absent. e yellow spot, on the contrary, the cones are abun- and close set, becoming at the same time longer and slender, while rods are scanty, and are found only



139.—Pigmented Epithelium of the Human Retina. (Max Schultze.) Highly magnified.

a, cells seen from the outer (choroidal) surface ; *b*, two cells seen side-ways with fine processes on their inner side ; *c*, a cell still in connection with the layer of rods of the retina.

rds its margin. In the centre of the *macula lutea* . 138) the layer of fibres of the optic nerve ppears, and all the other layers, except that of the s, become extremely thin.

The outer ends of the rods and cones lie buried among in fine processes of those pigment cells, adjacent to choroid coat, to whose existence we have previously ded (pp. 396, 414). When seen from the surface by h they are in contact with the choroid, these cells ent the appearance of small black hexagons arranged sort of mosaic (Fig. 139, *a*.).

Seen sideways each cell is found to be provided with long, fine, hair-like processes, which stretch in towards the retina and envelop the outer ends of the rods and cones (Fig. 139, *b.c.*).

The rods and cones each consist of two parts, an **outer limb** and an **inner limb.** In the rods the outer limb is quite cylindrical or rod-shaped, and is transversely striated. The inner limb is about as long as the outer, but bulges out slightly in its middle part, so that it forms an elongated cylinder tapering at each end. The outer part of each inner limb is longitudinally striated. The inner end of each inner limb is prolonged into a fine filament, which carries a conspicuous nucleus, often marked transversely, and may be easily traced into the outer molecular layer (Fig. 140, *R.*).

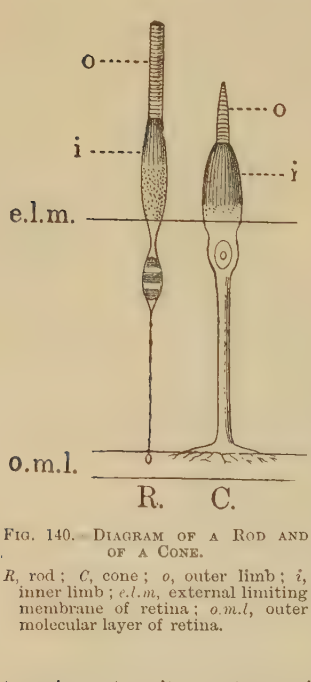


FIG. 140. DIAGRAM OF A ROD AND OF A CONE.

R, rod; *C*, cone; *o*, outer limb; *i*, inner limb; *e.l.m*, external limiting membrane of retina; *o.m.l*, outer molecular layer of retina.

The outer limb of a cone is much shorter than the outer limb of a rod and instead of being rod shaped, is conical and tapering to its outer point; this outer limb is transversely striated. The inner limb of each cone is thicker than the inner limb of a rod, but of the same general shape. It is striated longitudinally in its outer part and carries a large nucleus from which a thick fibre

s straight into the outer molecular layer of the
a (Fig. 140, *C.*).

The Sensation of Light.—The most notable
rty of the retina is its power of converting the
ions of ether, which constitute the physical basis of
into a stimulus to the fibres of the optic nerve.
entral ends of these fibres are connected with
n parts of the brain which constitute the *visual*
ium, just as other parts, as we have seen, constitute
ditory sensorium. The molecular disturbances set
the fibres of the optic nerve are transmitted to the
nce of the visual sensorium, and produce changes
latter, giving rise to the state of feeling which we
sensation of light.

e sensation of light, it must be understood, is
work of the visual sensorium, not of the retina;
if certain parts of the brain be destroyed or
ed, no sensation of light is possible even though
etina and indeed the whole optic nerve be intact;
ness is the result, because the visual sensorium
ot work.

ght, falling directly on the optic nerve, does not
e it; the fibres of the optic nerve, in themselves, are
ind as any other part of the body. But just as the
iar hair cells of the labyrinth, and the organ of
of the cochlea, are contrivances for converting
delicate vibrations of the perilymph and endolymph
impulses which can excite the auditory nerves,
he structures in the retina appear to be adapted
convert the infinitely more delicate pulses of the
niferous ether into stimuli of the fibres of the optic
e.

The "Blind Spot."—The sensibility of the different
s of the retina to light varies very greatly. The point
ntrance of the optic nerve is absolutely blind, as may
roved by a very simple experiment. Close the **left**
and look steadily with the **right** at the cross on

the page, held at ten or twelve inches distance from the eye.

The black dot will be seen quite plainly, as well as the cross. Now, move the book slowly towards the eye, which must be kept steadily fixed upon the cross; at a certain point the dot will disappear, but, as the book is brought still closer, it will come into view again. It results from optical principles that, in the first position of the book, the image of the dot falls between that of the cross (which throughout lies upon the yellow spot), and the entrance of the optic nerve: while, in the second position, it falls on the point of entrance of the optic nerve itself; and, in the third, it falls on the other side of that point. The three positions of the dot and cross, and of the resulting images of each on the retina, are shown in the accompanying figure, **141**.

So long as the image of the spot rests upon the entrance of the optic nerve, it is not perceived, and hence this region of the retina is called the *blind spot*. The experiment proves that the vibrations of the ether are not able to excite the fibres of the optic nerve itself.

10. **The Duration of a Luminous Impression.**—The impression made by light upon the retina not only remains during the whole period of the direct action of the light, but has a certain duration of its own, however short the time during which the light itself lasts. A flash of lightning is, practically, instantaneous, but the sensation of light produced by that flash endures for an appreciable period. It is found, in fact, that a luminous impression lasts for about one-eighth of a second; whence it follows,

f any two luminous impressions are separated by a interval, they are not distinguished from one er.

r this reason a "Catherine-wheel," or a lighted stick d round very rapidly by the , appears as a circle of fire; and spokes of a coach wheel at l are not separately visible, nly appear as a sort of opacity, lm, within the tire of the el.

e same fact is made use of in production of the "animated tographs" which are now so ectly shown. A series of in-taneous photographs of some ct in motion, taken at the rate nany per second, is printed on g transparent film of celluloid. film is then passed through a ic-lantern at such a rate that less than ten of the consecutive tographs are projected on to screen in each second. At this , the impression produced by photograph has not had time ie out before the next one pro-es its slightly different later t. The result is that the secutive pictures on the screen d in succession one into the r and so reproduce the appear-e of the original moving object.

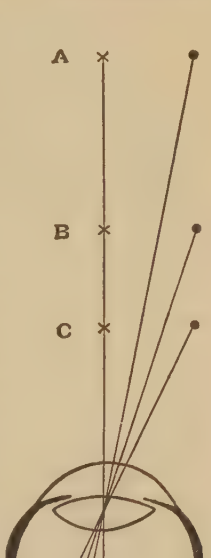


FIG. 141.

1. **Sensations of Light Produced without the ion of Light.**—The sensation of light may be excited ther causes than the impact of the vibrations of the iniferous ether upon the retina. Thus, an electric

shock sent through the eyeball may give rise to the appearance of a flash of light: and pressure on any part of the retina produces a luminous image, which lasts as long as the pressure, and is called a **phosphene.** If the point of the finger be pressed upon the outer side of the ball of the eye, the eyes being shut, a luminous image—which, in most cases, is dark in the centre, with a bright ring at the circumference (or, as Newton described it, like the "eye" in a peacock's tail-feather)—is seen; and this image lasts as long as the pressure is continued.

The sensation of light is, as already explained, the work of those parts of the brain which, as the visual sensorium, respond to the impulses reaching them through the optic nerve. The retina is the means of supplying the impulses to the sensorium and may be made to do so by light ordinarily, but also by other kinds of stimulation. But the visual sensorium itself may at times be affected by influences other than those which reach it from the retina. In this case also (subjective) luminous sensations of the most vivid and startling kind may be experienced, which give rise to delusive judgments of the most erroneous kind (see p. 437).

12. The Functions of the Rods and Cones.—The last paragraph raises a distinction between the "fibres of the optic nerve" and the "retina" which may not have been anticipated, but which is of much importance.

We have seen that the fibres of the optic nerve ramify in the inner fourth of the thickness of the retina, while the layer of rods and cones forms its outer fourth. The light, therefore, must fall first upon the fibres of the optic nerve, and, only after traversing them, can it reach the rods and cones. Consequently, if the fibrillæ of the optic nerve themselves are capable of being affected by light, the rods and cones can only be some sort of supplementary optical apparatus. But, in fact, it is the rods and cones which are affected by light, while the fibres of the

nerve are themselves insensible to it. The evidence hich this statement rests is :—

The blind spot is full of nerve fibres, but has no or rods.

The yellow spot, where the most acute vision is ed, is full of close-set cones, but has no nerve

) If one goes into a dark room with a single small t candle, and, looking towards a dark wall, moves ight up and down, close to the outer side of one eye, to allow the light to fall very obliquely into the eye, of what are called **Purkinje's figures** is seen. is a vision of a series of diverging, branched, dark, times reddish, lines on an illuminated field, and in nterspace of two of these lines is a sort of cup-shaped . The branched lines are the images of shadows wn by the retinal blood-vessels, and the disk is that he shadow thrown by the edge of the yellow spot. he candle is moved up and down, the lines shift their ion, as shadows do when the light which throws them ges its place.

ow, as the light falls on the inner face of the retina, the images of the vessels to which it gives rise shift r position as it moves, whatever constitutes the end- n, through which light stimulates the fibres of the c nerve, must needs lie on the other, or outer, side of vessels. But the fibres of the optic nerve lie among vessels, and the only retinal structures which lie out- them are the nuclear layers and the rods and cones.

) Just as, in the skin, there is a limit of distance in which two points give only one impression, so there minimum distance by which two points of light falling he retina must be separated in order to appear as And this distance corresponds pretty well with the eter of a cone.

he image of the retinal blood-vessels may be also very ily seen by looking at a bright surface, such as the

frosted globe of a burning lamp or a white cloud on a sunny day, through a pinhole in a card. When the card is moved *rapidly from side to side*, but so as to keep the pinhole always within the limits of the *width of the pupil*, the retinal blood vessels are "seen" as a fine branched network of black lines in the bright field of vision.

13. Sensations of Colour and Colour-blindness.— We have spoken of the eye so far simply as the instrument by which luminous sensations arise when the retina is stimulated; as an instrument which enables us to appreciate the position of a source of light, and differences in the intensity of the light which it emits or reflects, and hence to perceive objects in the world around us as regards their position, shape and size. But the objects we see are characterised by something more than mere shape and size; they differ also in respect of what we call their colour.

When we look at a rainbow we are conscious of seven broadly distinct kinds of colour-sensations; these are red, orange, yellow, green, blue, indigo-blue and violet, and when ordinary white light is passed through a prism and then allowed to fall into the eye we experience the same seven coloured sensations. The prism has, in fact, resolved the light into its several coloured constituents, and these are known as the "colours of the spectrum." Each colour which we recognise as such is characterised, just as in the case of sounds, by certain qualities; these are (i) **Hue**, or colour as we ordinarily use the word to denote what we call reds, greens, blues and so on. This quality is dependent on the wave-length of the ethereal vibrations which are giving rise to the sensation, and hence corresponds to the "pitch" of a sound. (ii) **Intensity** or **brightness**. This depends on the amount of light which falls on the retina in a given time and corresponds to the loudness of a sound. (iii) **Saturation**, or the amount of admixture with white light. Thus we speak of a colour as being "pale" if mixed with much

e and as being "deep," "rich," or "full" if highly
ated, *i.e.* unmixed with white.

e colours of objects depend on the power they possess
sorbing some of the constituents of ordinary white
and allowing others to pass or to be reflected. Thus
e of glass is red if it allows the red rays to pass to
ye and stops the others. Similarly the colour of an
te red object is due to an absorption of the spectral
rs other than red by the superficial layer of the
ct and the reflection of the unabsorbed red rays from
nternal parts.

hen white light has been split up into its coloured
tituents by means of a prism, these may be gathered
again by a second prism, suitably placed, and
mbined to make white light. In this experiment the
ral colours of the spectrum are *mixed* once more after
ng been sorted out or separated, and the mixing is a
ical process. But colours may also be mixed *physio-
ally* by taking advantage of that persistence of luminous
essions to which we have already drawn attention
23). Thus if the several colours of the spectrum are
ed in sectors on a circular disc and the disc is made
in rapidly round its centre, the sensations due to
colour are blended together and the disc appears
e. The instrument used in this mode of mixing
rs is called a "*colour top*" and the principle it
dies will be not unfamiliar to most people in the
of a common toy.

the use of a colour top it is at once possible to mix
nerely all the spectral colours but any two or three
nem. Experimenting in this way with pairs of
rs we find that there are several pairs which when
l give rise to the sensation of white : thus red and
, orange and blue, yellow and indigo-blue, greenish-
v and violet. Colours which when mixed in this way
irs give white are known as **complementary
urs**, and every colour has some other colour which

is complementary to it. If instead of mixing the colours in pairs we mix them in threes, then it becomes still more easy to produce a resultant white. Thus by mixing red, green and blue, with due regard to the relative amount and intensity of each, an excellent white is readily obtained. But these three colours enable us to do more than merely produce white. By properly adjusting the proportions of each on the disc of the colour-top we can easily produce an orange and a yellow, as also a violet. In other words these three colours and their mixtures give rise to all the several kinds of colour-sensation which we derive from a spectrum. Further, by suitable mixture of these colours, together with white or black, we can produce the other colours which we see in natural objects around us but which are wanting in the spectrum. Thus purple is extremely common in the world and can be made at once by mixing red and blue. Hence these three colours have come to be regarded as **primary colours**, and we may speak of the sensations to which they give rise as primary sensations.

The foregoing considerations lead at once to the view that all our sensations of colour may be regarded as the outcome of a very limited number (three) of simple or **primary sensations** corresponding to **red, green** and **blue**. In accordance with this fact a theory has been put forward [1] that there are in the visual apparatus three kinds of nervous structure of which each corresponds to one of the primary colours and is most easily set in action by one of these colours. Thus the stimulation of one of them gives rise to one of the primary sensations, the *simultaneous* stimulation of all three to the same extent gives rise to the sensation of white and their simultaneous stimulation to varying degrees gives rise to all the other

[1] This theory was first propounded by an Englishman, Dr. Thomas Young, the originator of the undulatory theory of light. In later times it was adopted and amplified by Helmholtz, and is therefore known as the Young-Helmholtz theory.

sations of colour of which we are at any time scious.

t recent years another theory has been started in se support very much may be said.[1] It resembles the ious one inasmuch as it also assumes that all our sen- ns of colour result from a limited number of primary sations. But it differs in the number and selection he primary colours. Thus according to this theory re are **three pairs** of primary sensations arising from e pairs of primary colours : these are **red-green, low-blue, white-black.** Further, this theory mes the existence in the visual apparatus of three ds of **visual substance** of which each corre- nds to one of the above pairs of colours, and ssumes that these substances may be made, some- t in the same way as the sensitive salts on a photo- phic plate, to undergo a *destructive* change by the action ight in such a way as to give rise to the sensations of , yellow and white. Finally it supposes that the other ee antagonistic sensations arise from the subsequent *structive* building up again of their visual substances ich must take place as soon as the luminous cause of ir destructive change has been removed. Thus the aking down of the red-green visual substance gives rise the sensation of red, and its building up again to the sation of green, and similarly for the other two pairs. Both these theories attempt to account for observed ts, and each goes a long way in doing so ; but neither them accounts completely for all the facts of colour ion. Neither may we enter into any discussion heir respective merits, for such discussion would be less if it were not lengthy and detailed, and its ricacy would be still further out of place in an elemen- y work which excludes as far as possible all debatable tter.

The excitability of the retina is readily exhausted.

[1] This is the theory of Hering, now Professor at Leipzig.

Thus, looking at a bright light rapidly renders the part of the retina on which the light falls, insensible; and on looking from the bright light towards a moderately lighted surface, a dark spot, arising from a temporary blindness of the retina in this part, appears in the field of view. If the bright light be of one colour, the part of the retina on which it falls becomes insensible to the rays of that colour, but not to the other rays of the spectrum. This is the explanation of the appearance of what are called **after-images**. For example, if, as in the form in which the experiment is most commonly made, a bright *red* wafer be stuck upon a sheet of white paper, and steadily looked at for some time with one eye, when the eye is turned aside to the white paper a *greenish* spot will appear, of about the size and shape of the wafer. The red image has, in fact, fatigued the part of the retina on which it fell for red light, but has left it sensitive to the remaining coloured rays of which white light is composed. But we know that if from the variously coloured rays which make up the spectrum of white light we take away all the red rays, the remaining rays together make up a sort of green. So that, when white light falls upon this part, the red rays in the white light having no effect, the result of the operation of the others is a greenish hue. The colour of the after image is thus of necessity *complementary* to that of the object looked at. If the wafer be *green*, the after-image is of course *red*.

Colour-blindness.—Most people agree very closely as to differences between different colours and different parts of the spectrum. But there are exceptions. Thus a certain number of persons see very little difference between the colour which most people call red, and that which most people call green. Such *colour-blind* persons are unable to distinguish between the leaves of a cherry-tree and its fruit by the colour of the two; they are only aware of a difference of shape between the two. Cases of this "red-blindness" or "red

n " blindness are not uncommon ; but another form olour-blindness in which blue and yellow cannot be nguished from each other is much more rare ; and rarer, though of undoubted occurrence, are the cases hose who are *wholly* colour-blind, *i.e.* to whom all urs are mere shades of one tint.

his peculiarity of colour-blindness is simply un- nate for most people, but it may be dangerous if owingly possessed by engine-drivers or sailors, parti- rly since red-green colour-blindness is most common red and green are exactly the two colours ordinarily for signals. It probably arises either from a defect he retina, which renders that organ unable to respond to rent kinds of luminous vibrations, and consequently nsible to red, yellow, or other rays, as the case may ; or the fault may lie in the visual sensorium itself.

or ordinary purposes colour perception may be most ly and successfully tested by asking the person under emination to make matches between skeins of coloured l. In this way it is found that a red-green colour-blind son matches a red with a green skein. For a detailed estigation of the sensations of the colour-blind more t observations by help of the spectrum are necessary.

he phenomena of colour-blindness can, to a certain ent at least, be explained according to either of the ories of colour-vision which have been given above. us by the Young-Helmholtz theory a red-green colour- nd person lacks either the red-perceiving or the green- ceiving structures normally present either in the na or the visual sensorium. According to the theory Hering they lack the red-green visual substance.

LESSON X

THE COALESCENCE OF SENSATIONS WITH ONE ANOTHER AND WITH OTHER STATES OF CONSCIOUSNESS

1. Sensations may be Simple or Composite.—In explaining the functions of the sensory organs, we have hitherto confined ourselves to describing the means by which the physical agent of a sensation is enabled to irritate a given sensory nerve; and to giving some account of the simple sensations which are thus evolved.

Simple sensations of this kind are such as might be produced by the irritation of a single nerve-fibre, or of several nerve-fibres by the same agent. Such are the sensations of contact, of warmth, of sweetness, of an odour, of a musical note, of whiteness, or redness.

But very few of our sensations are thus simple. Most of even those which we are in the habit of regarding as simple, are really compounds of different simultaneous sensations, or of present sensations with past sensations, or with those feelings of relation which form the basis of judgments. For example, in the preceding cases it is very difficult to separate the sensation of contact from the judgment that something is touching us; of sweetness, from the idea of something in the mouth; of sound or light, from the judgment that something outside us is shining or sounding.

The sensations of smell are those which are least complicated by accessories of this sort. Thus, particles

usk diffuse themselves with great rapidity through nasal passages and give rise to the sensation of a rful odour. But beyond a broad notion that the r is in the nose, this sensation is unaccompanied ny ideas of locality and direction. Still less does e rise to any conception of form, or size, or force, succession, or contemporaneity. If a man had ther sense than that of smell, and musk were the odorous body, he could have no sense of *outness* – wer of distinguishing between the external world and elf.

ntrast this with what may seem to be the equally le sensation obtained by drawing the finger along the , the eyes being shut. This act gives one the ation of a flat, hard surface outside one's self, which ation appears to be just as simple as the odour of k, but is really a complex state of feeling compounded

) Pure sensations of contact.

) Pure muscular sensations of two kinds,—the one ng from the resistance of the table, the other from the ns of those muscles which draw the finger along.

) Ideas of the order in which these pure sensations eed one another.

) Comparisons of these sensations and their order, the recollection of like sensations similarly arranged, h have been obtained on previous occasions.

) Recollections of the impressions of extension, flat-, &c., made on the organ of vision when these previous le and muscular sensations were obtained.

hus, in this case, the only pure sensations are those ntact and muscular action. The greater part of what all the sensation is a complex mass of present and llected sensations and judgments.

hould any doubt remain that we do thus mix up our sations with our judgments into one indistinguishable le, shut the eyes as before, and, instead of touching

the table with the finger, take a round lead pencil between the fingers, and draw that along the table. The "sensation" of a flat hard surface will be just as clear as before; and yet all that we touch is the round surface of the pencil, and the only pure sensations we owe to the table are those afforded by the muscular sense. In fact, in this case, our "sensation" of a flat hard surface is entirely a judgment based upon what the muscular sense tells us is going on in certain muscles.

A still more striking case of the tenacity with which we adhere to complex judgments, which we conceive to be pure sensations, and are unable to analyse otherwise than by a process of abstract reasoning, is afforded by our sense of roundness.

Any one taking a marble between two fingers will say that he feels it to be a single round body; and he will probably be as much at a loss to answer the question how he knows that it is round, as he would be if he were asked how he knows that a scent is a scent.

Nevertheless, this notion of the roundness of the marble is really a very complex judgment, and that it is so may be shown by a simple experiment. If the index and middle fingers be crossed, and the marble placed between them, so as to be in contact with both, it is utterly impossible to avoid the belief that there are two marbles instead of one. Even looking at the marble, and seeing that there is only one, does not weaken the apparent proof derived from touch that there are two.[1]

The fact is, that our notions of singleness and roundness are, really, highly complex judgments based upon a few simple sensations; and when the ordinary conditions of those judgments are reversed, the judgment is also reversed.

[1] A ludicrous form of this experiment is to apply the crossed fingers to the end of the nose, when it at once appears double; and in spite of the absurdity of the conviction the mind cannot expel it so long as the sensations last.

ith the index and the middle fingers in their ordinary
tion, it is of course impossible that the outer sides
ch should touch opposite surfaces of one spheroidal
. If, in the natural and usual position of the fingers,
outer surfaces simultaneously give us the impression
pheroid (which itself is a complex judgment), it is
nature of things that there must be two spheroids.
when the fingers are crossed over the marble, the
side of each finger is really in contact with a
roid ; and the mind, taking no cognizance of the
ng, judges in accordance with its universal experience,
two spheroids, and not one give rise to the sensations
h are perceived.

Judgments are Delusive, not Sensations. — nomena of the kind described in the preceding on are not uncommonly called *delusions of the senses ;* there is no such thing as a fictitious, or delusive, ation. A sensation must exist to be a sensation, and exists, it is real and not delusive. But the judgments form respecting the causes and conditions of the ations of which we are aware, are very often erroneous delusive enough ; and such judgments may be ght about in the domain of every sense, either by icial combinations of sensations, or by the influence nusual conditions of the body itself. The latter give to what are called *subjective sensations.*

ankind would be subject to fewer delusions than they if they constantly bore in mind their liability to false gments due to unusual combinations, either artificial natural, of true sensations. Men say, "I felt," "I rd," "I saw" such and such a thing, when, in ninety-e cases out of a hundred, what they really mean is, t they judge that certain sensations of touch, hearing, sight, of which they were conscious, were caused by h and such things.

. **Subjective Sensations.**—Among *subjective sensations* hin the domain of touch, are the feelings of creeping

and the prickling of the skin, which may sometimes be due to certain states of the circulation, but probably more frequently to processes going on in the central nervous system. The subjective evil smells and bad tastes which accompany some diseases are, in a similar way, very probably due to disturbances in the brain in the central end-organs of the nerves of smell and taste.

Many persons are liable to what may be called *auditory spectra*—music of various degrees of complexity sounding in their ears, without any external cause, while they are wide awake. I know not if other persons are similarly troubled, but in reading books written by persons with whom I am acquainted, I am sometimes tormented by hearing the words pronounced in the exact way in which these persons would utter them, any trick or peculiarity of voice, or gesture, being, also, very accurately reproduced. And I suppose that everyone must have been startled, at times, by the extreme distinctness with which his thoughts have embodied themselves in apparent voices.

The most wonderful exemplifications of subjective sensation, however, are afforded by the organ of sight.

Any one who has witnessed the sufferings of a man labouring under *delirium tremens* (a disease produced by excessive drinking), from the marvellous distinctness of his visions, which sometimes take the forms of devils, sometimes of creeping animals, but almost always of something fearful or loathsome, will not doubt the intensity of subjective sensations in the domain of vision.

But in order that illusive visions of great distinctness should appear, it is not necessary for the nervous system to be thus obviously deranged. People in the full possession of their faculties, and of high intelligence, may be subject to such appearances, for which no distinct cause can be assigned. An excellent illustration of this is the famous case of Mrs. A. given by Sir David Brewster in his *Natural Magic*. This lady was subject to un-

lly vivid auditory and ocular spectra. Thus on one sion she saw her husband standing before her and ng fixedly at her with a serious expression, though e time he was at another place. On another occa- she heard him repeatedly call her, though at the he was not anywhere near. On another occasion aw a cat in the room lying on the rug; and so vivid he illusion that she had great difficulty in satisfying lf that really there was no cat there. The whole unt is well worthy of perusal.

is obvious that nothing but the singular courage and intellect of Mrs. A. prevented her from becoming a of ghost stories of the most excellently authenti- d kind. And the particular value of her history lies s showing, that the clearest testimony of the most npeachable witness may be quite inconclusive as to objective reality of something which the witness has .

Irs. A. undoubtedly saw what she said she saw. The ience of her eyes as to the existence of the apparitions, of her ears to those of the voices, was, in itself, as fectly trustworthy as their evidence would have been the objects really existed. For there can be no doubt exactly those parts of her retina which would have n affected by the image of a cat, and those parts of auditory organ which would have been set vibrating her husband's voice, or rather the portions of the sorium with which those organs of sense are connected, e thrown into a corresponding state of activity by ne internal cause.

What the senses testify is neither more nor less than the t of their own affection. As to the cause of that affec- n they really say nothing, but leave the mind to form own judgment on the matter. A hasty or superstitious rson in Mrs. A.'s place would have formed a wrong dgment, and would have stood by it on the plea that he must believe her senses."

4. Delusions of Judgment.—The delusions of the judgment, produced not by abnormal conditions of the body, but by unusual or artificial combinations of sensations, or by suggestions of ideas, are exceedingly numerous, and, occasionally, are not a little remarkable.

Some of those which arise out of the sensation of touch have already been noted. We do not know of any produced through smell or taste, but hearing is a fertile source of such errors.

What is called **ventriloquism** (speaking from the belly), and is not uncommonly ascribed to a mysterious power of producing voice somewhere else than in the larynx, depends entirely upon the accuracy with which the performer can simulate sounds of a particular character, and upon the skill with which he can suggest a belief in the existence of the causes of these sounds. Thus, if the ventriloquist desire to create the belief that a voice issues from the bowels of the earth, he imitates with great accuracy the tones of such a half-stifled voice, and suggests the existence of some one uttering it by directing his answers and gestures towards the ground. These gestures and tones are such as would be produced by a given cause ; and no other cause being apparent, the mind of the bystander insensibly judges the suggested cause to exist.

The delusions of the judgment through the sense of sight—*optical delusions*, as they are called—are more numerous than any others, because such a great number of what we think to be simple visual sensations are really very complex aggregates of visual sensations, tactile sensations, judgments, and recollections of former sensations and judgments.

It will be instructive to analyse some of these judgments into their principles, and to explain the delusions by the application of these principles.

5. The Inversion of the Visual Image.—*When we look at an external object, the image of the object falls on*

retina at the end of the visual axis, i.e. *a line joining object and the retina and traversing a particular region the centre of the eye. Conversely, when a part of the na is excited, by whatever means, the sensation is rred by the mind to some cause outside the body in the rtion of the visual axis.*

When we look at an external object which is felt by the n to be in a given place, the image of the object falls a certain part of the retina. Conversely, when a of the retina is excited, by whatever means, the sensa- is referred by the mind to some cause outside the body pying such a position that its image would fall on that

t is for this reason that when a phosphene is created pressure, say on the outer and lower side of the eye- l, the luminous image appears to lie above, and to the er side of, the eye. Any external object which could duce the sense of light in the part of the retina pressed n must, owing to the inversion of the retinal images e p. 403), in fact occupy this position ; and hence the d refers the light seen to an object in that position.

The same kind of explanation is applicable to the parent paradox that, while all the pictures of external ects are certainly inverted on the retina by the refract- media of the eye, we nevertheless see them upright. is difficult to understand this, until one reflects that retina has, in itself, no means of indicating to the nd which of its parts lies at the top, and which at the ttom ; and that the mind learns to call an impression the retina high or low, right or left, simply on account the association of such an impression with certain ncident tactile impressions. In other words, when one t of the retina is affected, the object causing the affec- n is found to be near the right hand ; when another, left ; when another, the hand has to be raised to ch the object ; when yet another, it has to be depressed reach it. And thus the several impressions on the

retina are called right, left, upper, lower, quite irrespectively of their real positions, of which the mind has, and can have, no cognizance.

6. **Single Objects give rise to Single Images.**—*When an external body is ascertained by touch to be simple, it forms but one image on the retina of a single eye; and when two or more images fall on the retina of a single eye, they ordinarily proceed from a corresponding number of bodies which are distinct to the touch.*

Conversely, the sensation of two or more images is judged by the mind to proceed from two or more objects.

If two pin-holes be made in a piece of cardboard at a distance less than the diameter of the pupil, and a small object like the head of a pin be held pretty close to the eye, and viewed through these holes, two images of the head of the pin will be seen. The reason of this is, that the rays of light from the head of the pin are split by the card into two minute pencils, which pass into the eye on either side of its centre, and, on account of the nearness of the pin to the eye, meet the retina before they can be united again and brought to one focus. Hence they fall on different parts of the retina, and each pencil of rays being very small, makes a tolerably distinct image of its own of the pin's head on the retina. Each of these images is now referred outward (p. 439) and two pins are apparently seen instead of one. A like explanation applies to *multiplying glasses* and *doubly refracting* crystals, both of which, in their own ways, split the pencils of light proceeding from a single object into two or more separate bundles. These give rise to as many images, each of which is referred by the mind to a distinct external object.

7. **The Judgment of Distance and Size by the Brightness and Size of Visual Images.**—*Certain visual phenomena ordinarily accompany those products of tactile sensation to which we give the name of size, distance, and form. Thus, other things being alike, the space of the retina*

ed by the image of a large object is larger than that ed by a small object; while that covered by an object near is larger than that covered by the same object distant; and, other conditions being alike, a near is more brilliant than a distant one. Furthermore, adows of objects differ according to the forms of their ces, as determined by touch.

nversely, if these visual sensations can be produced, inevitably suggest a belief in the existence of objects ient to produce the corresponding tactile sensations.

hat is called *perspective*, whether *solid* or *aërial* in ing, or painting, depends on the application of these iples. It is a kind of visual ventriloquism—the ter putting upon his canvas all the conditions requisite he production of images on the retina, having the size, ive form, and intensity of colour of those which would ally be produced by the objects themselves in nature. the success of his picture, as an imitation, depends the closeness of the resemblance between the images oduces on the retina, and those which would be pro- d by the objects represented.

o most persons the image of a pin, at three or four es from the eye, appears blurred and indistinct— eye not being capable of adjustment to so short a s. If a small hole be made in a piece of card, the mferential rays which cause the blur are cut off, and image becomes distinct. But at the same time it is nified, or looks bigger, because the image of the pin, pite of the loss of the circumferential rays, occupies a h larger extent of the retina when close than when ant. All convex glasses produce the same effect— le concave lenses diminish the apparent size of an ect, because they diminish the size of its image on the na.

Objects, as is well known, appear larger when seen in a In this case the actual size of the image on the na is the same as if there were no fog. But the indis-

tinctness with which the object is seen leads to the wrong conclusion that it is situated at some considerable distance from the observer. Hence the judgment is formed that the object is large, because if it were not large it could not, *at the apparently greater distance*, produce an image on the retina of the size it does.

The moon, or the sun, when near the horizon appears very much larger than when it is high in the sky. This is usually said to be due to the fact that when in the latter position we have nothing to compare it with, and the small extent of the retina which its image occupies suggests small absolute size. But as it sets, we see it passing behind great trees and buildings which we know to be very large and very distant, and yet it occupies a larger space on the retina than they do. Hence the vague suggestion of its larger size. But this has really very little to do with the delusion, for the appearance is the same if the sun or moon is seen near the horizon over the open sea, where no comparison with other objects is possible. Probably one cause of the delusion is that when low down the sun or moon is seen less distinctly, on account of mist and vapour, and thus "looks" large for the same reason that a man seen in a fog appears unduly big, or the delusion may be due to the fact that to most people the distance from them to the horizon appears greater than the distance straight above them to the summit of the vault of the heavens (or the zenith). Hence though the actual size of the image of the sun or moon on the retina is the same whether they be low down or high up, the idea that they are further off when low down suggests that they are of greater size.

8. **Judgment of Form by Shadows.**—If a convex surface be lighted from one side, the side towards the light is bright—that turned from the light, dark, or in shadow ; while a concavity is shaded on the side towards the light, bright on the opposite side.

If a new half-crown, or a medal with a well-raised head

its face, be lighted sideways by a candle, we at once the head to be raised (or a *cameo*) by the disposition he light and shade; and if an *intaglio*, or medal on h the head is hollowed out, be lighted in the same its nature is as readily judged by the eye.

t now, if either of the objects thus lighted be viewed a convex lens, which inverts its position, the light dark sides will be reversed. With the reversal the ment of the mind will change, so that the cameo will garded as an intaglio, and the intaglio as a cameo; he light still comes from where it did, but the cameo ars to have the shadows of an intaglio, and *vice versâ*. ompletely, however, is this interpretation of the facts tter of judgment, that if a pin be stuck beside the al so as to throw a shadow, the pin and its shadow, g reversed by the lens, will suggest that the direction he light is also reversed, and the medals will seem to what they really are.

The Judgment of Changes of Form.—*Whenever external object is watched rapidly changing its form, a inuous series of different pictures of the object is im-sed upon the same spot of the retina.*

onversely, if a continuous series of different pictures of object is impressed upon one part of the retina, the mind es that they are due to a single external object, under-g changes of form.

his is the principle of the curious toy called the *thau-trope*, or "zootrope," or "wheel of life," by the help which, on looking through a hole, one sees images of glers throwing up and catching balls, or boys playing leapfrog over one another's backs. This is managed painting at intervals, on a disc of card, figures and glers in the attitudes of throwing, waiting to catch, and hing; or boys "giving a back," leaping, and coming position after leaping. The disc is then made to te before an opening, so that each image shall be sented for an instant, and follow its predecessor before

the impression of the latter has died away. The result is that the succession of different pictures irresistibly suggests one or more objects undergoing successive changes—the juggler seems to throw the balls, and the boys appear to jump over one another's backs. The same explanation holds good for the "animated photographs." (See p. 423)

10. Single Vision with Two Eyes. Corresponding Points.—*When an external object is ascertained by touch to be single, the centres of its retinal images in the two eyes fall upon the centres of the yellow spots of the two eyes, when both eyes are directed towards it; but if there be two external objects, the centres of both their images cannot fall, at the same time, upon the centres of the yellow spots.*

Conversely, when the centres of two images, formed simultaneously in the two eyes, fall upon the centres of the yellow spots, the mind judges the images to be caused by a single external object; but if not, by two.

This seems to be the only admissible explanation of the facts, that an object which appears single to the touch and when viewed with one eye, also appears single when it is viewed with both eyes, though two images of it are necessarily formed; and on the other hand, that when the centres of the two images of one object do not fall on the centres of the yellow spots, both images are seen separately, and we have double vision. In squinting, the axes of the two eyes do not converge equally towards the object viewed. In consequence of this, when the centre of the image formed by one eye falls on the centre of the yellow spot, the corresponding part of that formed by the other eye does not, and double vision is the result.

For simplicity's sake we have supposed the images to fall on the centre of the yellow spot. But though vision is distinct only in the yellow spot, it is not absolutely limited to it; and it is quite possible for an object to be seen as a single object with two eyes, though its image fall on the two retinas outside the yellow spots. All tha

ecessary is that the two spots of the retinas on which Images fall should be similarly disposed towards the res of their respective yellow spots. Any two points of two retinas thus similarly disposed towards their re- tive yellow spots (or more exactly to the points in which isual axes end), are spoken of as **corresponding nts**; and any two images covering two corresponding s are conceived of as coming from a single object. It bvious that the inner (or nasal) side of one retina *esponds* to the outer (or cheek) side of the other.

1. **The Judgment of Solidity.**—*When a body of lerate size, ascertained by touch to be solid, is viewed with h eyes, the images of it, formed by the two eyes, are essarily different (one showing more of its right side, the r of its left side). Nevertheless, they coalesce into a mon image, which gives the impression of solidity.*

Conversely, if the two images of the right and left ects of a solid body be made to fall upon the retinas of two eyes in such a way as to coalesce into a common ge, they are judged by the mind to proceed from the le solid body which alone, under ordinary circumstances, mpetent to produce them.

The *stereoscope* is constructed upon this principle. atever its form, it is so contrived as to throw the images two pictures of a solid body, such as would be ained by the right and left eye of a spectator, on to h parts of the retinas of the person who uses the reoscope as would receive these images, if they really ceeded from one solid body. The mind immediately ges them to arise from a single external solid body, and s such a solid body in place of the two pictures.

The operation of the mind upon the sensations presented t by the two eyes is exactly comparable to that which es place when, on holding a marble between the finger thumb, we at once declare it to be a single sphere 434). That which is absolutely presented to the mind by sense of touch in this case is by no means the sensa-

tion of one spheroidal body, but two distinct sensations of two convex surfaces. That these two distinct convexities belong to one sphere, is an act of judgment, or process of unconscious reasoning, based upon many particulars of past and present experience, of which we have, at the moment, no distinct consciousness.

LESSON XI

HE NERVOUS SYSTEM AND INNERVATION

1. **The General Arrangement of the Nervous stem.**—The sensory organs are, as we have seen, the nnels through which particular physical agents are bled to excite the sensory nerves with which these gans are connected ; and the activity of these nerves is denced by that of the central organ of the nervous tem, which activity becomes manifest as a state of nsciousness—the sensation.

We have also seen that the muscles are instruments by ich a motor nerve, excited by the central organ with ich it is connected, is able to produce motion.

The sensory nerves, the motor nerves, and the central gan, constitute the greater part of the *nervous system*, ich, with its function of *innervation*, we must now study newhat more closely, and as a whole.

The nervous apparatus consists of two sets of nerves d nerve-centres, which are intimately connected together d yet may be conveniently studied apart. These are the **rebro-spinal** system and the **sympathetic** system. he former, or central nervous system, consists of the **ain** (see Fig. 1), including with this the **spinal bulb** **medulla oblongata**, and **spinal cord** and the **anial** and **spinal nerves**, which are connected with s axis. The latter comprises the chain of **sym-thetic ganglia**, the nerves which they give off, and e various cords by which they are connected with one

another and with the cerebro-spinal nerves. (See Fig. 142.)

Nerves are made up entirely of **nerve-fibres**, the structure of which is somewhat different in the cerebro-spinal and in the sympathetic systems. (See p. 454.) Nerve centres, on the other hand, are composed of **nerve-cells** mingled with nerve-fibres. (See p. 462.) Such nerve-cells are found in various parts of the brain and spinal cord, in the sympathetic ganglia, and also in the ganglia belonging to spinal nerves as well as in certain sensory organs, such as the retina and the internal ear.

2. The Investing Membranes of the Cerebro-Spinal System.—The brain and spinal cord lie in the cavity of the skull and spinal column, the bony walls of which cavity are lined by a very tough fibrous membrane serving as the periosteum of the component bones of this region, and called the **dura mater.** This is composed of a thick layer of densely interwoven fibres of connective tissue, with which a small amount of elastic tissue is mixed. The brain and spinal cord themselves are closely invested by a very *vascular* membrane of fibrous connective tissue called **pia mater.** The numerous blood vessels supplying these organs run for some distance in the pia mater, and where they pass into the substance of the brain or cord the fibrous tissue of the pia mater accompanies them to a greater or less depth.

Between the *pia mater*, and the *dura mater*, lies another delicate membrane, called the **arachnoid** membrane. These three membranes are connected with each other at various points, and the arachnoid, which is not only very delicate, but also less regular than the other two, divides the space between the dura and pia mater into two spaces each containing fluid, and each more or less lined by a delicate epithelium. The space between the dura mater and the arachnoid, often called the **subdural space,** is nowhere very large ; but the space between the arachnoid and the pia mater, often called the **subarachnoid**

ce, though small and insignificant in the region of brain, becomes large in the region of the spinal cord, here contains a considerable quantity of fluid, called **ebro-spinal fluid.** This fluid has the appearance rdinary lymph, but there the resemblance ends; for ro-spinal fluid contains only a minute amount of ids (globulins), does not clot as true lymph does, and ains a peculiar reducing substance, which is, however, a sugar.

The Arrangement and General Structure of the nal Cord and the Roots of the Spinal Nerves. The al cord (Fig. 142) is a column of greyish-white soft stance, extending from the top of the spinal canal, re it is continuous by means of the spinal bulb with brain, to about the second lumbar vertebra, where it ers off into a filament. Starting at the level of the tion of the atlas vertebra with the skull, the spinal gives off laterally thirty-one pairs of **spinal nerves** se trunks pass out of the spinal canal by apertures ween the vertebræ, called the **intervertebral amina,** and then divide and subdivide, their ultimate nches going for the most part to the muscles and to skin. Each nerve originates from the cord by two s, consequently there are twice as many roots as there spinal nerves (Fig. 144). After their exit from the al canal the spinal nerves become connected with a n of ganglia which lies parallel to the spinal cord and stitutes the sympathetic nervous system (Fig. 142), ch will be described later on.

ransverse sections of the cord show that a deep, ewhat broad, fissure, the **anterior fissure** (Fig. 143, livides it in the middle line in front, nearly down to entre: and a similar deeper but narrower cleft, the **terior fissure** (Fig. 143, *2*), also extends nearly to centre in the middle line behind. The pia mater nds more or less into each of these fissures, and ports the vessels which supply the cord with blood.

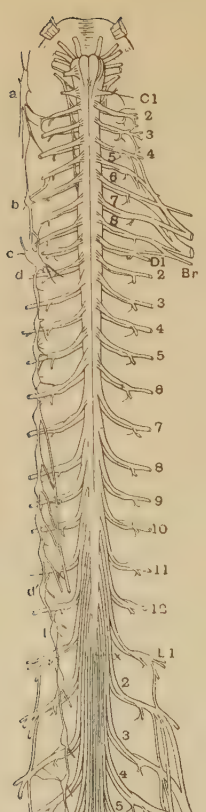


FIG. 142.—DIAGRAM, AS SEEN FROM THE FRONT, OF THE SPINAL CORD THE SPINAL NERVES, AND ON ONE SIDE OF THE SYMPATHETIC CHAIN OF GANGLIA. (AFTER ALLEN THOMSON.)

The numbers of the thirty-one spinal nerves are shown on the righ

nsequence of the presence of these fissures, only a
w bridge of the substance of the cord connects its
halves, and this bridge is traversed throughout its
length by a minute canal, the **central canal** of
ord (Fig. 143, *3*).

e lines of attachment of the roots of the spinal nerves
the cord longitudinally into three parts, called
tively the anterior, lateral and posterior columns
143, *8*, *7*, *6*), those roots which arise along the line
is nearer to the anterior surface of the cord being
n as the **anterior roots**; those which arise along
ther line are the **posterior roots** (Figs. 143 and

A certain number of anterior and posterior roots,
e same level on each side of the cord, converge and
anterior and posterior bundles, and then the two
les, anterior and posterior, coalesce into the **trunk**
spinal nerve; but before doing so, the posterior
le presents an enlargement—**the ganglion of the
erior root** (Fig. 144, *Gn.*).

transverse section of the spinal cord (Fig. 144, B,
Fig. 143), shows further that each half consists
wo substances—a **white matter** on the outside,
a greyish-red substance in the interior. And
grey matter, as it is called, is so disposed
in a transverse section, it looks, in each half,
thing like a crescent, with one end bigger than
ther, and with the concave side turned outwards.
two ends of each crescent are called its **horns** or

---

f the figure. *C*, 1-8, cervical; *D*, 1-12, thoracic (dorsal); *L*, 1-5,
r; *S*, 1-6, sacral; *Br*, brachial plexus; *Sc*, great sciatic nerve;
minal filament of spinal cord.
perior, *b*, middle, *c*, inferior cervical ganglion of the sympathetic
n; of these *c* is fused with *d* the first thoracic (dorsal) ganglion.
ne animals (dog and cat) the ganglion corresponding to *c*, the
r cervical ganglion of man, is fused with the *upper three* thoracic
a into a common ganglion called the "stellate" ganglion (see Figs.
St.G.) and the ganglion corresponding to *b*, the middle cervical
on of man, is in this case known as the inferior cervical ganglion.
he eleventh thoracic sympathetic ganglion; *l*, the first lumbar
on. The ganglia below *ss* are the sacral ganglia.

cornua, the one directed forwards being the anterior cornu (Fig. 143, *e e*); the one turned backwards the posterior cornu (Fig. 143, *a a*). The convex sides

FIG. 143. TRANSVERSE SECTION OF ONE-HALF OF THE SPINAL CORD (THE LUMBAR REGION), MAGNIFIED.

1, anterior fissure; 2, posterior fissure; 3, central canal; 4, and bridges connecting the two halves (posterior and anterior commissures 6, posterior column; 7, lateral column; 8, anterior column; 9, posteri root; 10, anterior root of nerve.

a a, posterior horn of grey matter; *e e e*, anterior horn of grey matt Through the several columns 6, 7, and 8, each composed of white matt are seen the prolongations of the pia mater, which carry blood-vess into the cord from the outside. The pia mater itself is seen over t whole of the cord.

rescents of the grey matter approach one another, and ined by the bridge which contains the central canal. portion of this bridge which lies immediately behind central canal is known as the **posterior grey missure**; that portion which lies in front of it as **anterior grey commissure.** The latter is rated from the inner end of the anterior fissure by a bridge of white matter known as the **anterior e commissure.** (See Figs. 143 and 150.)

ere is a fundamental difference in structure between

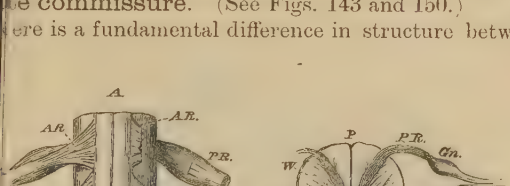


FIG. 144.—THE SPINAL CORD.

A front view of a portion of the cord. On the right side, the ior roots, *A.R*, are entire; on the left side they are cut, to show the rior roots, *P.R.*

A transverse section of the cord. *A*, the anterior fissure; *P*, the rior fissure; *G*, the central canal; *C*, the grey matter; *W*, the white r; *A.R.* the anterior root, *P.R.* the posterior root, *Gn.* the ganglion, *T*, the trunk, of a spinal nerve.

grey and the white matter. The white matter consists ost entirely of nerve-fibres supported in a delicate iework of connective tissue, and accompanied by d-vessels. Most of these fibres run lengthways in the , and consequently, in a transverse section, the white ter is really composed of a multitude of the cut ends hese fibres.

he grey matter, on the other hand, contains in addi- a number of nerve cells, some of them of considerable

These cells are wholly, or almost wholly, absent in white matter.

Many of the nerve-fibres of which the anterior roots ar composed may be traced into the anterior cornu, and indeed, into the nerve-cells lying in the cornu, whil those of the posterior roots, for the most part, enter o pass towards the posterior cornu.

4. The Minute Structure of Medullated Nerves.— The white matter of the spinal cord consists chiefly o nerve-fibres ; we may therefore, with advantage, consider

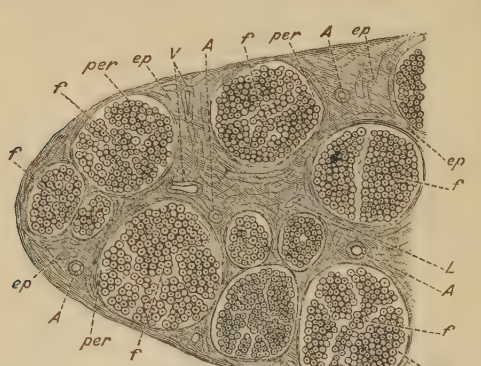


FIG. 145.—TRANSVERSE SECTION OF A MEDIUM-SIZED MEDULLATED NERVE

ep, *ep*, general connective tissue sheath or epineurium ; *f*, *f*, *f*, bundle of nerve-fibres bound together by the perineurium *per*, *per*, *per* ; *A*, *A*, blood-vessels ; *L*, lymphatic vessel.

the structure of these nerve-fibres before dealing in detai with the minute structure of the cord itself.

If a small piece of a nerve, which may be easily obtaine from the leg of a freshly killed frog or rabbit, be tease out with needles on a glass slide and examined under microscope it is seen to be made up chiefly of minut fibres. When the nerve has been suitably hardened i becomes possible to cut a transverse section of it ; if thi section be similarly examined the cut ends of the fibre

be readily seen as little circular dots arranged
groups which compose the larger part of the
on. These fibres are bound together in bundles,
ii are rounded as seen in section, by an external
th or case of connective tissue called the **peri-**
rium, from whose inner surface very delicate layers
nnective tissue pass in between the fibres of which
bundle is composed. The several bundles are
selves bound together by connective tissue to form
trunk of the nerve, and the whole nerve, thus built
f bundles of nerve-fibres, is surrounded and held
ther by an external layer of connective tissue.

he **nerve-fibres**, which are the essential elements of
nerve, vary in diameter from 2μ to 12μ or more. In the
g state they are very soft cylindrical rods of a glassy,
ner strongly refracting aspect. No limiting membrane
istinguishable from the rest of the substance of the
. but running through the centre of it a band of some-
t less transparency than the rest may be discerned.
intervals, the length of which varies, but is always
y times greater than the thickness of the rod, the
ve fibre presents sharp constrictions, which are termed
les (Fig. 146, A, *n* ; B. *n n*). Somewhere in the inter-
e between every two nodes, very careful examination
reveal the existence of a **nucleus** (Fig. 146, B. *n c*),
sted by more or less protoplasmic substance and
g in the substance of the rod, but close to the
ace.

s the fibre dies, and especially if it is treated with
ain re-agents, these appearances rapidly change.
The outermost layer of the fibre becomes recognisable
definite membrane, the **neurilemma**[1] (the so-called

[1] This word was formerly used to denote the whole nerve-case, now
d *perineurium*; but its similarity to the word *sarcolemma* led to
confusion in the minds of students. It is undoubtedly a whole-
rule never to use an old word in a new sense: but the striking
arity between the two words "neurilemma" and "sarcolemma,"
between the nerve-fibre sheath and the muscle-fibre sheath, seems an
uate excuse for an exception to the rule.

"primitive sheath" or "sheath of Schwann"). 2. The central band becomes more opaque, and sometimes appears marked with fine longitudinal striæ as if it were composed of extremely fine fibrillæ ; it is the **neuraxis** or **neuraxon** or **axis cylinder**. 3. Where the neuraxis traverses one of the nodes the neurilemma is seen to embrace it closely, but in the intervals between the nodes a curdy-looking matter, which looks white by reflected light, occupies the space between the *neurilemma* and the *neuraxis*. This is the **medulla** (the so-called "white substance of Schwann") largely composed of a complex fatty substance often spoken of as *myelin*. If the neurilemma of a fresh fibre is torn, the myelin flows out and forms irregular lumps as if it were viscous. The medulla sometimes breaks, by oblique lines (Fig. 146, C. *m'*), extending from the neuraxis to the neurilemma, into segments, the faces of which are obliquely truncated and fit closely against one another. These may be seen even in quite fresh and living nerve fibres. 4. The internodal nucleus is more sharply defined ; and it will be seen to be attached to the inner surface of the neurilemma.

The essential part of each fibre, regarded as an instrument for the transmission of that molecular disturbance which is spoken of as a "nervous impulse," is the neuraxis or axis-cylinder. This is suggested by the fact that the neuraxis alone is apparently continuous throughout each fibre, since it passes across each node ; but all doubt is removed when we find that the neuraxis alone provides the actual connection between the central nervous system and the distant structures to or from which the motor (efferent) or sensory (afferent) nerves run. Thus, if we follow along the course of a motor nerve, proceeding to its muscle, we find that it enters the perimysium (with which the superficial layer of the perineurium becomes continuous), and divides in the perimysial septa into smaller and smaller branches, each of which

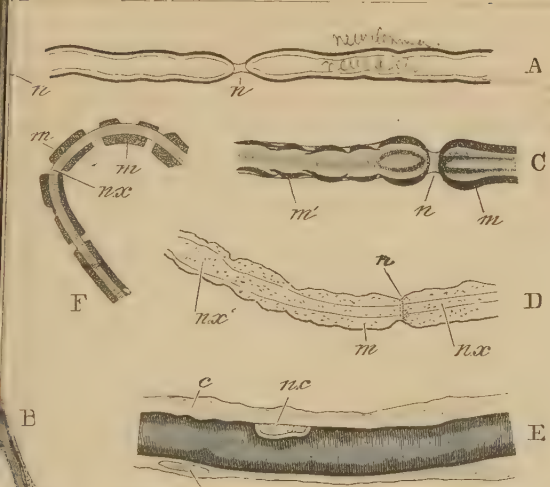


FIG. 146. TO ILLUSTRATE THE STRUCTURE OF NERVE FIBRES.

. A nerve fibre seen without the use of reagents, showing the uble contour" due to the medulla, and *n*, a node. Neither neuraxis neurilemma can be distinctly seen. (Magnified about 300 diameters.)

. A thin nerve fibre treated with osmic acid, showing, *n c*, nucleus h protoplasm, *p*, surrounding it, beneath the neurilemma; *n n*, the nodes marking out the segment to which the nucleus belongs. gnified 400 diameters.)

Portion of fibre (thicker than B), treated with osmic acid to show node *n*; *m*, the densely stained medulla; at *m'* the medulla is seen ded into segments. (Magnified 350 diameters.)

. Portion of nerve fibre treated to show the passage of the neuraxis, through the node, *n*; *m*, the medulla. At *n n'* the neuraxis is llen by the reagents employed and large and irregular. (Magnified diameters.)

Portion of nerve fibre treated with osmic acid, showing the nucleus, embedded in the medulla; *c*, fine perineurial sheath lying outside neurilemma; the outline of the latter can only be recognised over nucleus *n c*; the nucleus, *n c'*, belongs to this perineurial sheath. gnified 400 diameters.)

Portion of nerve fibre deprived of its neurilemma and showing the ulla broken up into separate fragments, *m m*, surrounding the axis, *n x*.

contains the continuation of a certain number of the fibres of the nerve trunk, bound up into a bundle by themselves. In these larger ramifications of the nerve trunk there is no branching of the nerve fibres themselves (at any rate as a rule), but merely a separation of the fibres of the compound nerve bundles. In the finer branches, however, the nerve fibres themselves may divide ; the division, *which always takes place at a node*, is generally dichotomous—that is, one fibre divides into two, each of these again into two, and so on. An ultimate branch consisting of one or two nerve fibres, or of one only, with a very delicate connective tissue envelope (Fig. 146, E *c*), passes to some single muscle fibre, and each nerve fibre applies itself to the outer surface of the sarcolemma. At this point, if it has not done so before, *the medulla disappears*, the neurilemma becomes continuous with the sarcolemma, and the *neuraxis* ending abruptly is applied to a disc of protoplasmic substance containing many nuclei, thus forming what is called a **motor end-organ** or **end-plate**,[1] which is interposed between the striated muscle substance and the sarcolemma at this point, Before ending the neuraxis divides and its divisions anastomose freely, but the exact relations of the various parts of the end-plate to the muscle-substance have not yet been clearly made out. The whole appear, however, to constitute an apparatus by which the molecular disturbances of the substance of the neuraxis (the essential part of the nerve) may be efficiently propagated to the substance of the muscle.

If, instead of following the motor nerve to its distribution in the muscle, we trace it the other way, towards the spinal cord, we shall find no alteration of any moment until we arrive at the point at which the anterior root enters the cord. From the finest branches of the motor nerve (in which, as has been stated, the nerve-fibres

[1] This is the arrangement in most vertebrated animals. In the frog the neuraxis branches out without entering a distinct motor end-plate.

nselves divide) to this point of entry each nerve-fibre ends ensheathed as *one continuous undivided neuraxis* long succession of internodal segments. At the point ntry into the cord the perineurium passes into the pia ter and the general connective tissue framework of the . The *neurilemma and the nodes disappear*. Often neuraxis can be traced towards the anterior horn of grey matter, invested only by a sheath of *medulla* ch gradually becomes thinner and thinner until at gth it *disappears*, and the fibre, thus reduced to its raxis, passes into one of the processes of one of the ge *nerve cells*, which lie in the anterior cornu of the y matter (see p. 463).

The neuraxis of a motor nerve-fibre, therefore, is in t an extremely fine and long process of a *nerve cell*, ich passes at its peripheral end into one or more *muscle res*; in other words, the nerve cell and the muscle cells are e central and peripheral end-organs of the nerve-fibre.

With one or two exceptions, sensory (afferent) nerve-res are not distinguishable by any structural character m motor nerve-fibres. Wherever special-sense ganules (p. 343) exist, the sensory fibres are connected th them by means of their neuraxis from which the urilemma and medulla have disappeared. If, as before, follow the sensory nerve-fibres back towards the inal cord, we find that they pass through the ganglion one of the posterior roots, and then enter the substance the cord, passing towards the posterior cornu. Like e motor nerve-fibres, they lose their noded neurilemma they enter the cord, so that in this case also it is again e neuraxis which provides the actually continuous con-ection between the sense-organ and the central nervous stem.

The neurilemma, with its nucleus and the medulla, may regarded as a covering which provides for the protec-on and nourishment of each successive length of the sentially important neuraxis or axis-cylinder.

5. The Minute Structure of the Spinal Cord and Spinal Ganglia.—The spinal cord consists, as already described, of a central canal surrounded by grey matter composed largely of nerve-cells, and arranged in two crescent-shaped masses. The grey matter is surrounded by white matter, consisting chiefly of medullated nerve-fibres, and the whole is invested by the pia mater composed of connective tissue.

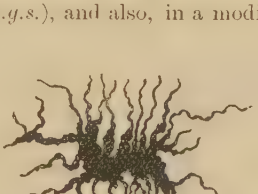
The pia mater carries the blood-vessels and lymphatics which supply the substance of the cord; it dips down into and completely fills the narrow so-called posterior fissure, and similarly lines the wider cavity of the anterior fissure. At frequent intervals, all over the surface of the cord, and in the fissures, the pia mater sends conspicuous prolongations (see Fig. 143) into the substance of the white matter, forming partitions or septa which run on the whole towards the grey matter, and thus carry the blood-vessels into the cord. These larger primary septa give off fine secondary septa, which still further subdivide the white matter, and provide for the more intimate distribution of minute blood-vessels throughout its substance. The inner ends of the septa are continued on into the grey matter for purposes similar to those which they subserve in the white matter.

The spaces in the white matter between the septa derived from the pia mater are filled by (i) medullated nerve-fibres, whose structure has been previously described, which run on the whole lengthwise or parallel to the long axis of the cord, and are supported by (ii) a fine felt-work of *extremely delicate* fibres, which constitutes what is known as the **neuroglia**, (*νεῦρον* = nerve, and *γλία* = glue) since it binds the nerve-fibres together. The fibres of the neuroglia are, in reality, processes from numberless minute cells, in which the body of each cell is extremely small, and the processes unusually numerous; these cells are known as neuroglia-cells (Fig. 147).

The processes of the neuroglia-cells are wrapped closely

and the nerve-fibres, and since they thus form a support d a covering for the fibres, the latter no longer need eir natural external covering; or, in other words, the rve-fibres of the white matter possess no neurilemma.

As in the white matter of the cord, so also in the grey tter, neuroglia occupies the spaces between the septa ived from the pia mater, and forms the supporting sis for the nervous constituents of the grey matter. he neuroglia is gathered into a specially well-marked ver immediately surrounding the central canal of the rd (Fig. 150, *c.g.s.*), and also, in a modified form, into a



IG. 147.—A NEUROGLIA-CELL FROM THE WHITE MATTER OF THE SPINAL CORD. (SCHÄFER.)

The body and processes of the cell appear black, since they were eply stained in order to bring out their details.

onspicuous somewhat transparent mass at the outer end f the *posterior* horn of the grey matter, where it is nown as the **substantia gelatinosa** of Rolando. See Fig. 150, *sg.*).

The most striking feature of the grey matter is the resence in its neuroglia of nerve cells, many of which re very large and conspicuous, while others are smaller, ut still very evident; these cells, together with the *mparative* absence of medullated nerve-fibres, and the resence of a closely interwoven net-work of non-edullated nerve-fibres, form the chief contrast between

the structure of the grey and the white matter of the spinal cord.

The Cells of the Grey Matter.—These cells are not scattered uniformly throughout the grey matter, but arranged rather in groups. The largest cells occur in the outer end of the anterior horn (see Figs. 143 and 150), and since these are typical, as regards the main features of their structure, of all the cells of the grey matter, we may take one of them for detailed description.

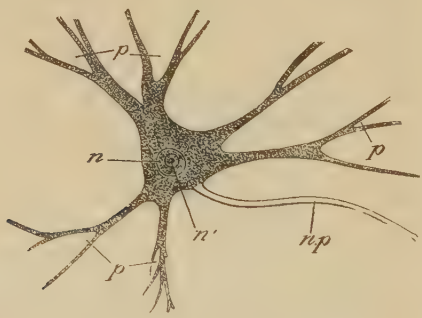
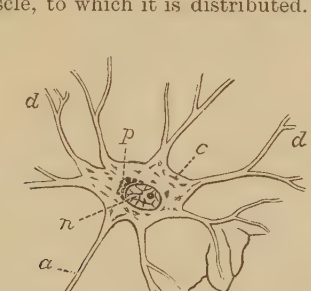


FIG. 148. A LARGE NERVE CELL FROM THE ANTERIOR HORN OF THE SPINAL CORD.

n, Nucleus; *n'*, small body, called the nucleolus, inside the nucleus; *p*, branched processes or dendrites; *n.p*, unbranched axis-cylinder process or axon continued into the neuraxis of a motor nerve fibre.

The body of each cell is large (varying in diameter from 50μ to 100μ; $\frac{1}{500}$ to $\frac{1}{250}$ of an inch), and contains a very conspicuous nucleus (Fig. 148). The cell-body is prolonged into a varying number (usually many) of processes called dendrites dividing and subdividing into branches, which may be traced to some distance from the cell, becoming finer and finer, and finally ending abruptly. Besides these branching processes the cell bears one process, the axis-cylinder process, which does not divide

his way, passes straight away from the cell and is covered by a layer of myelin or a medulla; its exit from the cord, it acquires additionally a ilemma or primitive sheath. In this way this ess becomes the axis cylinder or neuraxis of a allated nerve-fibre, and is continuous to the organ, lly a muscle, to which it is distributed.



149.—Diagram of a Typical Cell from the Grey Matter of the Spinal Cord. (Sherrington.)

nucleus; *d*, *d*, *d*, branched processes (dendrites) from the cell-body; igment; *c*, part of cell-body which stains very readily (chro- n); *a*, axis-cylinder process or neuraxon, which acquires first a ulla, *m*, and then (outside the cord) a neurilemma. represents the processes (dendrites) from a neighbouring cell inter- g with, but not joined on to, the processes of the cell figured.

he other cells of the grey matter are generally similar tructure to the one described, though smaller than the s of the anterior horn. Certain of them however ibit particular features, on which we need not dwell e.

he rest of the grey matter, apart from the neuroglia, nade up of an interlacing network of nerve fibres, which many are the processes of nerve cells, or ed (non-medullated) axis cylinders; but inter-

mixed with these are a certain number of *very fine* medullated nerve-fibres, and a few large medullated fibres.

The Differences in Structure of the Spinal Cord at Various Levels. These differences show themselves most conspicuously with respect to (i), the shape of the grey matter at various levels (ii), the position of the chief groups of nerve-cells in the grey matter, and (iii), the amount of white matter *relatively* to the grey matter at each level. The cord is widest in the cervical region, smallest in the thoracic (dorsal) region, and widens out again in the lumbar region. The chief structural differences to which we have alluded are very clearly indicated in Figure 150, which represents sections, drawn to scale, of (half) the spinal cord at the level of A the sixth thoracic (dorsal), B the sixth cervical, and C the third lumbar spinal nerves respectively.

The Structure of a Spinal Ganglion. A spinal ganglion is, as we have said (Fig. 144, *Gn.*), an elongated swelling on the posterior roots of the spinal nerves. In a longitudinal section it is seen to consist of an external sheath of connective tissue which encloses groups of large nerve cells, of which the largest group lies at its outer side. The nerve fibres which enter the distal end of the ganglion on their way to the spinal cord pass in bundles in between the groups of nerve cells, and a certain amount of connective tissue with accompanying blood-vessels and lymphatics, also passes in amongst the nerve cells and nerve fibres. Each nerve cell (Fig. 15) consists like a nerve cell of the spinal cord, of a large nucleus, with a nucleolus, and of a cell body; but the cell body is, in most cases at all events, prolonged into one process only, so that the whole cell is pear-shaped. This process soon acquires a medulla and a neurilemma; it thus becomes an ordinary medullated nerve fibre, which then divides into two fibres, one of which may be traced into the nerve trunk, and the other along the posterior

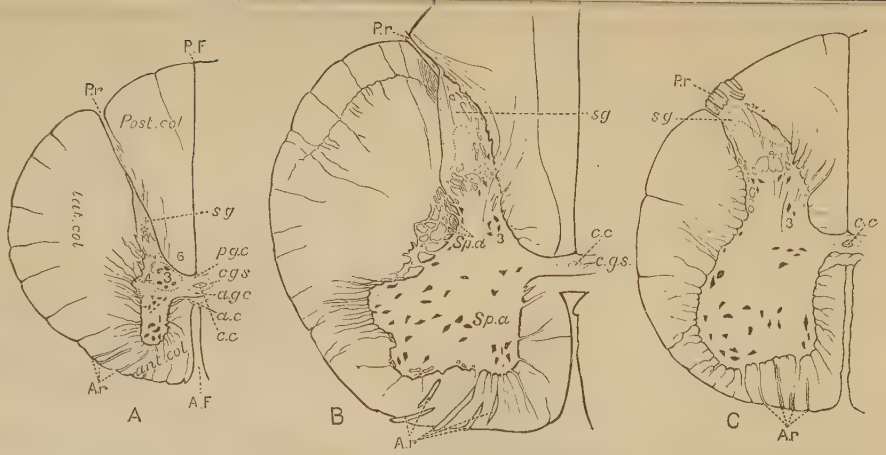


FIG. 150.—TRANSVERSE SECTIONS OF HALF THE SPINAL CORD, DRAWN TO SCALE, IN THE THORACIC (DORSAL), CERVICAL AND LUMBAR REGIONS. (AFTER SHERRINGTON.)

A, at the level of the sixth thoracic nerve; B, at the level of the sixth cervical nerve; C, at the level of the third lumbar nerve. *A.F.* anterior fissure; *P.F.* posterior fissure; *ant.col.*, *lat.col.*, *post.col.*, anterior, lateral and posterior columns of the white matter; *Ar*, anterior roots; *Pr*, posterior root of spinal nerve; *c.c*, central canal; *a.c*, anterior white commissure; *a.g.c*, anterior grey commissure; *p.g.c.* posterior grey commissure; *s.g*, *substantia gelatinosa* of Rolando; *c.g.s*, gelatinous substance surrounding the central canal.

1, cells of the anterior horn; 3, group of cells known as the vesicular column or column of Clarke; 6, cells of the posterior horn.

root to the spinal cord. Hence the nerve cells of the ganglion appear to be lateral appendages of the nerve fibres, forming a junction with them after the fashion of a T-piece. On the central side of the ganglion the fibres continue their course into the substance of the spinal cord towards the posterior horn. Like the motor nerves they lose their neurilemma as they enter the cord. Some of them pass on at once into the grey matter of the posterior horn; but the majority turn

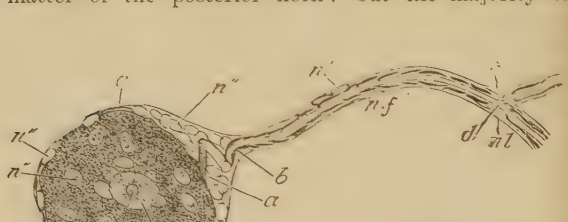


FIG. 151. - A NERVE CELL FROM THE GANGLION ON THE POSTERIOR ROOT OF A SPINAL NERVE.

n.c. the nerve cell, with *n*, nucleus, *n'*, nucleolus, *p*, protoplasmic body; *c*, capsule of the nerve cell; *n''*, nuclei of the capsule; *n.f.* the nerve fibre which, at the node, *d*, divides into two. At *a* the neuraxis of the fibre is lost in the substance of the cell; at *b* it acquires a medulla; at *n''* nuclei are seen on the fibre. At the division the neuraxis *d* is seen to divide, and besides the neurilemma, *n.l.*, the fibre has an additional sheath, *s*, continuous with the capsule of the nerve cell.

aside as they enter the cord and run upwards for some distance in the posterior column of the cord before they enter the grey matter.

Structurally we may regard the nerve fibres of the posterior roots of the spinal cord as taking their origin from one process of a cell in the spinal ganglion, in the same way that the fibres of the anterior root originate in one process of a nerve cell in the anterior horn of the grey

matter. This accounts for the peculiar way in which the fibres of the posterior root make their connection with the cord, and also for the most obvious function of the spinal ganglia of which we shall speak presently.

6. The Functions of the Roots of the Spinal Nerves.—If the trunk of a spinal nerve be irritated in any way (at *x* in Fig. 152), as by pinching, cutting, galvanising, or applying a hot body, two things happen : in the first place, all the muscles to which filaments of this nerve are distributed, contract ; in the second, pain is felt, and the pain is referred to that part of the skin to which fibres of the nerve are distributed. In other words, the effect of irritating the trunk of a nerve is the same as that of irritating its component fibres at their terminations.

The effects just described will follow upon irritation of any part of the *branches* of the nerve : except that when a branch is irritated, the only muscles directly affected, and the only region of the skin to which pain is referred, will be those to which that branch sends nerve-fibres. And these effects will follow upon irritation of any part of a nerve from its smallest branches up to the point of its trunk, at which the anterior and posterior bundles of root fibres unite.

If the *anterior bundle* of root fibres be irritated in the same way (at *y*, Fig. 152) only half the previous effects are brought about. That is to say, all the muscles to which the nerve is distributed contract, but no pain is felt.

So again if the *posterior, ganglionated bundle* be irritated (at *z*, Fig. 152) only half the effects of irritating the whole trunk is produced. But it is the other half ; that is to say, none of the muscles to which the nerve is distributed contract, but pain is referred to the whole area of skin to which the fibres of the nerve are distributed.

It is clear enough, from these experiments, that all the power of causing muscular contraction which a spinal nerve possesses, is lodged in the fibres which compose

its anterior roots; and all the power of giving rise to sensation, in those of its posterior roots. Hence the anterior roots are commonly called *motor*, and the posterior *sensory*.

The same truth may be illustrated in other ways. Thus, if, in a living animal, the anterior roots of a spinal nerve be cut, the animal loses all control over the muscles to which that nerve is distributed, though the sensibility of the region of the skin supplied by the nerve is perfect. If the posterior roots be cut, sensation is lost, and voluntary movement remains. But if both roots be cut, neither voluntary movement nor sensibility is any longer possessed

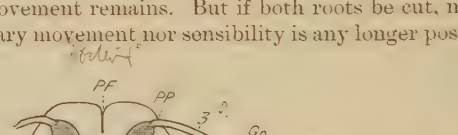


FIG. 152. - DIAGRAM TO ILLUSTRATE EXPERIMENTS IN PROOF OF THE FUNCTIONS OF THE SPINAL NERVE-ROOTS AND OF THE GANGLION ON THE POSTERIOR ROOT.

AF, anterior fissure of spinal cord; *PF*, posterior fissure; *AR*, anterior root of spinal nerve; *PR*, posterior root; *T*, trunk of spinal nerve; *Gn*, ganglion of posterior root.

by the part supplied by the nerve. The muscles are said to be paralysed; and the skin may be cut, or burnt, without any sensation being excited.

If, when both roots are cut, that end of the motor root which remains connected with the trunk of the nerve be irritated, the muscles contract; while, if the other end be so treated, no apparent effect results. On the other hand, if the end of the sensory root connected with the trunk of the nerve be irritated, no apparent effect is produced, while, if the end connected with the cord be irritated, pain immediately follows.

When no apparent effect follows upon the irritation of

ny nerve, it is not probable that the molecules of the nerve remain unchanged. On the contrary, it would appear that the same change occurs in all cases; but a motor nerve is connected with nothing that can make that change apparent save a muscle, and a sensory nerve with nothing that can show an effect but the central nervous system.

We have already explained (p. 463) that a fibre of the anterior root of a spinal nerve is really a prolongation of an axis cylinder process of a nerve cell in the anterior horn of the grey matter of the spinal cord. This being the case it is not at all surprising to find that the continued life of any of the efferent (motor) nerve fibres is dependent upon the continuance of their connection with the cells from which they arise. That this dependence does really exist is shown by the simple experiment of cutting an efferent (motor) nerve, and preventing the cut ends from reuniting. When this is done it is found that shortly after the operation, those (peripheral) *parts of the nerve beyond the point of section*, i.e., *whose connection with the cells of the spinal cord has been cut off*, undergo what is called a "degeneration." This degeneration shows itself by structural changes in the nerve fibres. The medulla breaks up into oily drops, the axis cylinder also breaks into pieces and the nuclei of the neurilemma increase in number, together with an increase in the amount of granular protoplasm, which lies near them. The fragments of the medulla are next largely absorbed and disappear, and their place is taken by the protoplasm and nuclei derived from the neurilemma. While these structural changes are taking place, and even before they become obvious, the irritability of the nerve becomes gradually less, so that soon the nerve makes no response to any stimulus which may be applied to it. But the changes we have described do not occur in that (central) part of the nerve which is still connected

with the cells of the spinal cord; this part does not degenerate in the same way. Thus if the anterior efferent (motor) root of one of the spinal nerves be cut at y (Fig. 152), all the fibres of that root beyond y towards and along the trunk of the nerve T degenerate, while the portion of the root between y and the spinal cord does not degenerate.

If, now, we apply the same method of experiment to the posterior root the following results are observed. When the root is cut at x (Fig. 152), the fibres of that root towards and along the trunk of the nerve T degenerate; the central parts connected with the ganglion do not. If, on the other hand, the posterior root is cut at z, then the part of the root which lies between z and the spinal cord degenerates, whereas the portion still connected with the ganglion does not. Evidently, then, the life of the fibres in the posterior root is dependent upon their continued connection with the ganglion of that root, that is to say with the cells of that ganglion, of which the fibres are processes, as we have previously explained. These facts lead to the inevitable conclusion that the ganglion on the posterior root is the structure upon which the proper nutrition of the afferent fibres depends, or, in other words, the one clear and definitely ascertained function of the ganglion is to provide for the nutrition of these efferent nerve fibres which originate from the processes of the nerve cells in the ganglion.

This method of determining and localising the nutritional centres from which nerve fibres grow is known as the "degeneration method,"[1] and has proved to be most helpful in determining the various "tracts," or paths in the spinal cord (and brain) along which nervous impulses of various kinds pass; with these we shall have to deal later on (see p. 484).

[1] Also as the "Wallerian method," after the name of the physiologist who first employed it.

7. The Physiological Properties of a Nerve. –It will be observed that in all the experiments described in the first part of the preceding section there is evidence that, when a nerve is irritated, a something which is spoken of as a **nervous impulse** and consists, probably, in a change in the arrangement of its molecules, is propagated along the nerve-fibres. If a motor or a sensory nerve be irritated at any point, contraction in the muscle, or sensation, (or some other corresponding event) in the central organ, immediately follows. But if the nerve be cut, or even tightly tied at any point between the part irritated and the muscle or central organ, the effect at once ceases, just as cutting a telegraph wire stops the transmission of the electric current or impulse. When a limb, as we say, "goes to sleep," it is frequently because the nerves supplying it have been subjected to pressure sufficient to interfere with the nervous conductivity of the fibres, that is their power to transmit nervous impulses. We lose voluntary control over, and sensation in, the limb, and these powers are only gradually restored as that nervous conductivity returns.

Having arrived at this notion of an impulse travelling along a nerve, we readily pass to the conception of a sensory nerve as a nerve which, when active, brings an impulse to the central organ, or is *afferent;* and of a motor nerve, as a nerve which carries away an impulse from the organ, or is *efferent.* It is very convenient to use these terms to denote the two great classes of nerves; for, as we shall find (p. 479), there are afferent nerves which are not sensory in the sense of giving rise to a change of consciousness, or sensation, while there are efferent nerves which are not motor, in the sense of inducing muscular contraction. The nerves, for example, by which the electrical fishes give rise to discharges of electricity from peculiar organs to which those nerves are distributed, are efferent, inasmuch as they carry impulses to the electric organs, but are not motor, inasmuch as

they do not give rise to movements. The pneumogastric when it stops the beat of the heart cannot be called a motor nerve, and yet is then acting as an efferent nerve. Similarly the nerves which cause the cells of a gland to commence secreting, such as those to the salivary glands, sweat glands, pancreas, &c., are not motor nerves but are strictly efferent as regards the direction in which they convey their impulses. It will, of course, be understood, as pointed out above, that the use of these words does not imply that when a nerve is irritated in the middle of its length, the impulses set up by that irritation travel only away from the central organ if the nerve be efferent, and towards it, if it be afferent. On the contrary, we have evidence that in both cases the impulses travel both ways. All that is meant is this, that the afferent nerve from the disposition of its two ends, in the skin, or other peripheral organs on the one hand, and in the central organ on the other, is of use only when impulses are travelling along it towards the central organ, and similarly the efferent nerve is of use only when impulses are travelling along it, away from the central organ.

There is no difference in structure, in chemical or in physical character, between afferent and efferent nerves. The impulse which travels along them requires a certain time for its propagation, and is vastly slower than many other movements—even slower than sound. (See p. 476.)

We know but little of the nature of a nervous impulse. We know that it may be started in a nerve by various artificial means such as by pinching or knocking the nerve, or by suddenly warming or cooling it, and, most readily, by stimulating the nerve electrically. And we suppose that by any of these means there is set up in that bit of nerve to which any one of the above "stimuli" is applied, a disturbance, which is then propagated in succession from one particle (or molecule) of the axis cylinder to the next, so that it ultimately reaches a point in the nerve remote from that in which it was started. In this

y we come to speak of a nervous impulse as due to
propagation of a "molecular disturbance" along a
ve. But this expression serves rather to hide our
rance than to explain what the impulse really is.

lectrical Properties of a Nerve. In the case of a
cle we saw (p. 297) that its entry into a state of (con-
ting) activity was accompanied by an easily recognised
age of shape, by chemical changes and by changes of
perature. Of these the first is of course entirely
iting in a nerve when it becomes active, *i.e.* is conveying
impulse, and the other two kinds of change have not
ar been shown to take place in a nerve. But we saw
that the contracting activity of a muscle is accom-
ied by an electrical disturbance ; a similar disturbance
es place in a nerve as the impulse sweeps along it, and
indeed the only evidence we possess of any change
ch accompanies the transmission of that impulse.
nce in a nerve this electrical phenomenon becomes of
reme interest and merits a short consideration.

f a piece of nerve, as for instance the sciatic nerve
Fig. 90), from a freshly-decapitated frog, is removed
n the body and suitably examined, it is found that
cut end of the nerve is *electrically negative* as compared
h any other point of the nerve nearer to its middle or
ator. Hence if one end B (Fig. 153), of the nerve and
middle point C are brought into contact with the
minals a, b, of a sensitive galvanometer[1] G, the needle
his instrument is at once deflected in a direction which
ws that an electric current is passing (through the
anometer) from the middle of the nerve to the cut
. If, now, when the needle has come to rest under the
uence of this current, the end A of the nerve be
nulated at x, the needle of the galvanometer is seen to
ng back towards the position it occupied before it was
cted by the current from the nerve. This means that as

[1] A galvanometer is an instrument used for the detection and
urement of electric currents.

the impulse which was started by the stimulus at x passes under the terminal b, that part of the nerve on which this terminal rests, becomes momentarily less electrically positive, that is to say *becomes electrically negative as compared with its condition before the passage of the impulse.* This statement holds equally good when the terminal b is applied to any other point of the nerve, either towards A or towards B, any difference in the result of stimulating the nerve at x being merely one of degree (as regards the extent to which the needle of the galvanometer moves), and not of kind (as to the direction in which the needle moves). Hence we may say without any possibility of

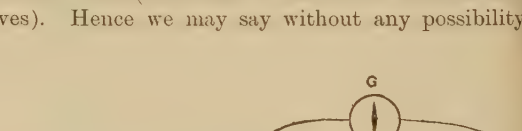


FIG. 153.—TO SHOW ARRANGEMENT OF A NERVE AND GALVANOMETER FOR EXPERIMENTS ON THE ELECTRICAL PROPERTIES OF A NERVE.

AB, a piece of nerve; G, a galvanometer connected by wires and the electrodes a, b, with the end B and the middle point C of the nerve.

doubt that when an impulse travels along a nerve each point of the nerve becomes electrically negative as the impulse reaches that point; and conversely we may use this electrical change in the nerve as unfailing evidence of the passage of an impulse along it. Apart from this electrical change we have no other means, such as exist in the case of a muscle, of determining when a nerve enters into a state of activity during the passage of an impulse.

The Rate of Transmission of a Nervous Impulse.—By means of a complicated arrangement of apparatus it is possible to determine very exactly the interval of time which elapses between the moment at which the stimulus is applied to the nerve at x (Fig. 153) and the instant at

ch the needle of the galvanometer begins to move as result of the passage of the impulse, started at x, er the terminal b at the point C. If now we measure length of the piece of nerve between x and b we can nce calculate the rate at which the impulse travels the nerve. Thus if the distance from x to b is 25 metres (1 inch), about ·00089 of a second elapses re the impulse started at x makes itself obvious as an rical disturbance at b. That is to say the impulse els at the rate of about 28 metres or 90 feet per nd in the nerve of a frog.

he rate of transmission of an impulse along a (motor) e may also be determined in the following way, using uscle nerve preparation such as is figured on page 298. muscle is suspended from a clamp, as shown in 154; a light horizontal lever is attached by a hook to tendon at the lower end of the muscle, so that when muscle is made to contract the free end of the lever es upwards and thus indicates the moment at which contraction of the muscle commences. The sciatic e is then arranged in such a way that it may be ulated either at a point x (Fig. 154) as close as possible its junction with the muscle, or at a point y as far y as possible from the muscle. By the use of suitable aratus it is easy to measure the interval of time which ses between the moment of applying the stimulus at x the moment at which the end of the lever begins to e. This is found to be, in an ordinary experiment, ut $\frac{1}{100}$th of a second. If now the nerve is stimulated , it is found that the end of the lever begins to move ıtly later than it did when the stimulus was applied ; that is to say, the muscle begins to contract rather when its nerve is stimulated at y than at x. This rence can only be due to the fact that *when the ulse is started at y it takes longer to reach the muscle than n it is started at x.* Since the length of the piece of e between y and x is known by direct measurement,

it becomes a simple matter to calculate the rate at which the impulse travels from y to x. The result thus obtained agrees quite closely with the one arrived at in the experiment previously described in which a galvanometer was used, namely 28 metres or 90 feet per second.

The rate at which an impulse travels along a nerve is closely dependent on the temperature of the nerve, and

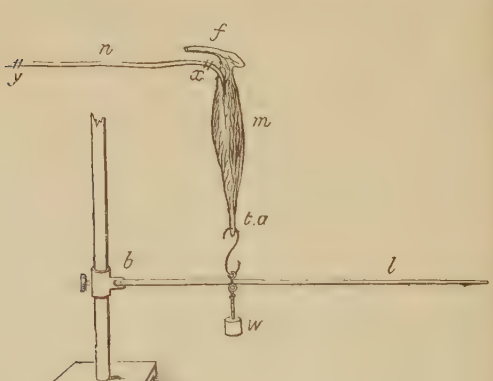


FIG. 154.—ARRANGEMENT OF NERVE, MUSCLE AND LEVER FOR DETERMINING THE VELOCITY OF A NERVOUS IMPULSE.

f, femur; m, muscle; $t.a$, tendon; l, lever, movable about the end b; w, weight to keep the muscle stretched; n, the nerve; x and y, the two points at which the nerve is stimulated

diminishes as the nerve is cooled; thus, by cooling a frog's nerve the rate may be reduced to as little as 1 metre (3 feet) per second. Hence it is not surprising that when experiments are made on the nerves of a warm-blooded human being, the rate of transmission is found to be somewhat greater, viz., 33 metres (or rather over 100 feet) per second, than in the cold-blooded frog.

The most efficient stimulus which can be *artificially*

ied to a nerve for starting an impulse along it, is, as ave said (p. 472), an electrical stimulation. Further, e have seen, each point of the nerve undergoes an rical change, as the impulse reaches that point. e two facts frequently give rise to the entirely eous idea that a nervous impulse is of the nature of an ric current, similar to that which passes along a wire, ed for telegraphy. But this is by no means the case, , without going into any other more abstruse reasons, we shown that the rate at which an impulse travels along rve is on an average about 30 metres, or 100 feet, per nd, whereas we know that electricity travels along a at a rate such that the transmission of signals over wires of an ordinary land-line is practically instan- ous. Even in one of the cables across the Atlantic an (2,500 miles in length) only two-tenths of a second se after contact is made with the battery at one end re the effect can be first detected at the other end. , if a nerve could be used for transmitting an impulse signal from, say, London to Liverpool (200 miles), signal would take nearly three hours (176 minutes) reach its destination, travelling as it does at the of 100 feet per second. We have spoken of ervous impulse as a "molecular disturbance" pro- ated along a nerve. And if we may illustrate what ean by this expression, by likening the process of transmission of a nervous impulse to the transmission y other condition with which most people are familiar, might compare it with the passage of the explosion g a train of gunpowder when a spark is applied to one of it. In this case the spark merely sets up a ecular change or disturbance in the grains of powder hich it is applied ; the change thus set up leads to a lar change in the next neighbouring grains and so on g the whole train of powder, so that ultimately the lt of applying the spark *at one end* makes its arance as a similar result *at the other end* of the train.

Similarly in a nerve we may regard the stimulus as setting up a change, whose nature we do not as yet understand, at the point to which it is applied; this change sets up a similar change in the next neighbouring particles of the nerve, and so on until it finally appears at the furthest end of the nerve. But a nerve, unlike the train of gunpowder, relays itself so long as it is alive, as soon as the impulse has passed along it, whereas the train of powder is "dead" after the passage of the explosion, and must be artificially relaid for further use.

8. The Properties or Functions of the Spinal Cord.—Up to this point our experiments have been confined to the nerves. We may now test the properties of the spinal cord in a similar way. If the cord be cut across (say in the middle of the back), the legs and all the parts supplied by nerves which come off below the section, will be *insensible*, and *no effort of the will can make them move*; while all the parts above the section will retain their ordinary powers.

When a man hurts his back by an accident, the cord is not unfrequently so damaged as to be virtually cut in two, and then *insensibility* and *paralysis* of the lower part of the body ensue.

If, when the cord is cut across in an animal the cut end of the portion below the division, or away from the brain, be irritated, violent *movements* of all the muscles supplied by nerves given off from the lower part of the cord take place, but *no sensation* is felt by the brain. On the other hand, if that part of the cord, which is still connected with the brain, or better, if any afferent nerve connected with that part of the cord be irritated, *sensations ensue*, as is shown by the movements of the animal; but in these movements the *muscles* supplied by the nerves coming from the spinal cord below the cut *take no part*; they remain perfectly quiet.

Thus, it may be said that, in relation to the brain the

d is a great mixed motor and sensory nerve. But is also much more.

Reflex Action through the Spinal Cord.—If the trunk a spinal nerve be cut through, so as to sever its nection with the cord, an irritation of the skin to ch the sensory fibres of that nerve are distributed duces neither motor nor sensory effect. But if the cord cut through anywhere so as to sever its connection with brain, irritation applied to the skin of the parts sup- d with sensory nerves from the part of the cord *below section*, though it gives rise to no sensation, may pro- e violent motion of the parts supplied with motor nerves m the same part of the cord.

Thus, in the case supposed above, of a man whose legs paralysed and insensible from spinal injury, tickling soles of the feet will cause the legs to kick out convul- ely. And as a broad fact, it may be said that, so long both roots of the spinal nerves remain connected with cord, irritation of any afferent nerve is competent to e rise to excitement of some, or the whole, of the efferent rves so connected.

If the cord be cut across a second time at any distance ow the first section, the efferent nerves below the second will no longer be affected by irritation of the afferent rves above it—but only of those below the second tion. Or, in other words, in order that an afferent pulse may be converted into an efferent one by the nal cord, the afferent nerve must be in uninterrupted terial communication with the efferent nerve, by means the substance of the spinal cord.

This peculiar power of the cord, by which it is com- ent to convert afferent into efferent impulses, is that ich distinguishes it physiologically, as a central organ, m a nerve, and is called **reflex action**. It is a power sessed by the grey matter, and not by the white stance of the cord.

The number of the efferent nerves which may be

excited by the reflex action of the cord, is not regulated alone by the number of the afferent nerves which are stimulated by the irritation which gives rise to the reflex action. Nor does a simple excitation of the afferent nerve by any means necessarily imply a corresponding simplicity in the arrangement and succession of the reflected motor impulses. Tickling the sole of the foot is a very simple excitation of the afferent fibres of its nerves ; but in order to produce the muscular actions by which the legs are drawn up, a great multitude of efferent fibres must act in regulated combination. In fact, in a multitude of cases a reflex action is to be regarded rather as the result of a dormant activity of the spinal cord awakened by the arrival of the afferent impulse, as a sort of orderly explosion fired off by the afferent impulse, than as a mere rebound of the afferent impulse into the first efferent channels open to it.

The various characters of these reflex actions may be very conveniently studied in the frog. If a frog be *decapitated*, or, better still, if the spinal cord be divided close to the head, and the brain be destroyed by passing a blunt wire into the cavity of the skull, the animal is thus deprived (by an operation which, being almost instantaneous, can give rise to very little pain) of all consciousness and volition, and yet the spinal cord is left intact. At first the animal is quite flaccid and apparently dead, no movement of any part of the body (except the beating of the heart) being visible. This condition, however, being the result merely of the so-called shock of the operation, very soon passes off, and then the following facts may be observed.

So long as the animal is untouched, so long as no stimulus is brought to bear upon it, no movement of any kind takes place : *volition is wholly absent.*

If, however, one of the toes be gently pinched, the leg is immediately drawn up close to the body.

If the skin between the thighs around the anus be

pinched, the legs are suddenly drawn up and thrust out again violently.

If the flank be very gently stroked, there is simply a twitching movement of the muscles underneath; if it be more roughly touched, or pinched, these twitching movements become more general along the whole side of the creature, and extend to the other side, to the hind legs, and even to the front legs.

If the digits of the front limbs be touched, these will be drawn close under the body as in the act of clasping.

If a drop of vinegar or any acid be placed on the top of one thigh, rapid and active movements will take place in the leg. The foot will be seen distinctly trying to rub off the drop of acid from the thigh. And what is still more striking, if the leg be held tight and so prevented from moving, the other leg will begin to rub off the acid. Sometimes if the drop be too large or too strong, both legs begin at once, and then frequently the movements spread from the legs all over the body, and the whole animal is thrown into convulsions.

Now all these various movements, even the feeblest and simplest, require a certain combination of muscles, and some of them, such as the act of rubbing off the acid, are in the highest degree complex. In all of them, too, a certain purpose or end is evident, which is generally either to remove the body, or part of the body, from the stimulus, from the cause of irritation, or to thrust away the offending object from the body: in the more complex movements such a purpose is strikingly apparent.

It seems, in fact, that in the frog's spinal cord there are sets of nervous machinery destined to be used for a variety of movements, and that a stimulus passing along a sensory nerve to the cord sets one or the other of these pieces of machinery at work.

Thus one important function of the spinal cord is to serve as an independent nervous centre, capable of originating combined movements upon the reception of the

impulse of an afferent nerve, or rather, perhaps, a group of such independent nervous centres.

In all these reflex actions of the spinal cord, the structures necessary for their performance are, as already pointed out (p. 340), a sensory surface, an afferent nerve, a portion of the grey matter of the cord, an efferent nerve, and a muscle or group of muscles. In the case of the headless frog, the actions are of course quite involuntary, and performed unconsciously, and the same remark holds good in the case of a man whose spinal cord is so injured as to be practically cut in two. But even in an uninjured healthy man, similar reflex actions, although now under the control of the will, are strikingly manifest, and play an important part in his everyday life. Thus the act of walking, though started by the will, is subsequently a reflex action. When engaged in conversation or buried in thought, a person walks with all his ordinary dexterity, but in entire unconsciousness of the action. In this case the afferent impulses are largely started from the stimulation of the skin of the feet and legs which results from the varying pressure and contact with the ground. Hence the staggering gait in cases where, as a result of disease, the chain of structures requisite for the liberation of the reflexes is broken, as for instance by disease of the posterior (afferent) roots of the spinal nerves. In such cases walking is frequently possible only as the result of *looking* at the ground; this accords with the fact that even in health afferent impulses started in the sensory surface (retina) of the eye play an important part in giving rise to the reflexes of walking. But, on the other hand, blind persons walk with no little dexterity.

Again, the actions of micturition and defæcation are really reflex actions carried out by the spinal cord, as soon as they have been started by the will; here the sensory surfaces are the mucous membrane of the bladder or rectum, the necessary stimulus being supplied as the result of their distension by the accumulated urine or fæces.

Using the expression reflex action in a rather wider and more general sense we may here again draw attention to the importance of these actions to the working and welfare of the body as regards the relationships of its internal mechanisms. Thus we have seen that certain parts of the spinal bulb, or medulla, which for our present purpose may be regarded as part of the spinal cord, are connected with the heart (cardio-inhibitory centre), blood-vessels (vaso-motor centre), and respiratory muscles (respiratory centre) in such a way that impulses arising in outlying parts of the body, lead reflexly to such modified activity of each of the above systems, as may from time to time be necessary. (See pages 76, 70, 161).

Reflex action is a property of the central nervous system which is not confined to the spinal cord alone, or to the spinal bulb to which we have just extended it, but is also a marked characteristic of the varied activities of the brain. But to this point we shall return later on.

The Paths of Conduction of Afferent and Efferent Impulses along the Spinal cord. The spinal cord has a further most important function beyond reflex action, namely that of transmitting nervous impulses, as a great mixed motor and sensory nerve leading from the brain, between the brain and the various organs, such as the muscles and the skin, with which the spinal nerves are connected. When we move a foot, certain nervous impulses, starting in some part of the cerebral hemispheres, pass down along the whole length of the spinal cord as far as the roots of the spinal nerves going to the legs, and passing along the fibres of the anterior bundles of these roots find their way to the muscles which move the foot. Similarly, when the sole of the foot is touched, afferent impulses travel in the reverse way upward along the spinal cord to the brain. And the question arises, in what manner do these efferent and afferent impulses travel along the spinal cord?

This question is one very difficult to answer, and indeed, a complete and exact statement, is not, at present, possible. But we must now explain the method by which most of our present information has been obtained, and point out the chief and most definite facts which have been arrived at.

We have seen previously (p. 469) that when a nerve is cut, a structural change of its fibres starts at the cut. This is spoken of as a "degeneration," and since it indicates a breakdown in the proper nutrition of those fibres which are seen to degenerate may, as in the case of the roots of the spinal nerves, be used to determine the relationship of nerve fibres to the centres upon which their nutrition depends. The white matter of the spinal cord is composed of fibres which are in all essentials the same as those of an ordinary medullated nerve, and these fibres of the white matter may similarly degenerate when cut off from the centres on which their nutrition depends. Hence, if the whole spinal cord be cut across transversely, or if transverse cuts be made into any part, or the whole of any one or more of the columns of white matter of which the cord is so largely made up, degenerative changes may start from the point of section, and by the course they pursue up and down the cord, enable us to follow the course of certain fibres or bundles of fibres in that white matter. Now this is exactly what does happen when the cord is cut, and this "degeneration method" has provided the best means for answering the question as to how and along what paths afferent and efferent impulses travel up and down the spinal cord.

When the cord is cut across degenerative changes take place in parts of the white matter, both above and below the point of section. These changes only affect limited parts of the white matter, and the parts which are affected *above* the cut, that is up towards the brain, are different in position from the parts which are affected *below* the point of section. The changes which start from the

ut and take place *upwards* along the spinal cord, towards he brain, are spoken of as **ascending** degenerations ; hose which are observed to occur *downwards* from below he section, are known as **descending** degenerations, the erms ascending and descending being thus used to denote uctural changes which start from the section and pass up wards or down from the brain respectively. Moreover, nce the parts which degenerate are limited as to their ansverse sectional area while running for very considerble distances along the white matter of the spinal cord, ey are usually spoken of as "tracts," and since these acts serve very definitely for the transmission of apulses up and down the cord, they denote very efinite paths of conduction along the spinal cord.

Having thus explained the method of experimenting, e may now state the chief results obtained by its pplication.

(A). *Tracts of ascending degeneration.*

(i). **The Median-Posterior or Postero-median Tract.**— This tract occupies the median part of the posterior hite columns of the spinal cord, adjacent to the posterior ssure, in each half of the cord. (Fig. 155, *p.m.*, *p.m.*).

The degeneration which marks out this tract follows not nly upon sections of the cord itself, but more especially om cutting the posterior roots of the spinal nerves ; it is herefore the result of a severance of the fibres in this art of the cord from their nutritive centres in the cells of he ganglion on the posterior root. Hence it marks the ourse of fibres passing up the cord from the posterior oots, and denotes the path along which afferent (sensory) mpulses travel up from the spinal nerves. Since these erves are given off all along the cord, the median-osterior tract is necessarily found to exist throughout the hole extent of the cord, and may be traced up into he spinal bulb, where it ends on the side up which it asses.

(ii). **The Cerebellar Tract.**—This tract lies in the outer and hinder part of the lateral columns (Fig. 155, *Cb.*, *Cb.*). The degeneration which marks its course results solely from sections of the cord itself, and not of any of the spinal nerve roots. It begins in the lower end of the cord at the level of the second lumbar nerve, passes straight up to the spinal bulb and then into the cerebellum by means of the *inferior peduncle* (see p. 501) of this part of the

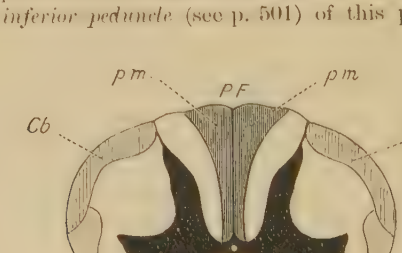


FIG. 155.—DIAGRAM TO SHOW THE POSITION OF TRACTS OF ASCENDING DEGENERATION IN THE WHITE MATTER OF THE SPINAL CORD AT THE LEVEL OF THE FIFTH CERVICAL NERVE.

A.F. anterior fissure; *P.F.* posterior fissure; *p.m.*, *p.m.* the median posterior tract, or tract of fibres from the posterior roots of the spinal nerves; *Cb*, *Cb*, the cerebellar tract; *asc. a.l.*, *asc. a.l.* the ascending antero-lateral tract.

The grey matter of the cord is shaded black.

brain. The fibres in this tract are believed to originate from processes of those cells in the grey matter which form a conspicuous group at the base of the dorsal horn, and are known as **Clarke's column.** (See Fig. 150, 3).

(iii). **The Ascending Antero-lateral Tract.** This tract, like the cerebellar, can only be made evident as the result of injury to the cord itself. It lies in the outer and anterior part of the lateral column (Fig. 155, *asc. a.l.*, *asc. a.l.*) and commences rather lower down in the cord

than does the cerebellar tract, but like the latter runs up to the spinal bulb, and enters the cerebellum by means of its *superior peduncle.*

B. *Tracts of descending degeneration.*

(i) **The Crossed Pyramidal Tract.**—This is a large and conspicuous tract in the inner and hinder part of the lateral column (Fig. 156, *Cr.p.*, *Cr'.p'.*).

It extends along the whole length of the cord, passing down into the cord from the spinal bulb. The fibres of

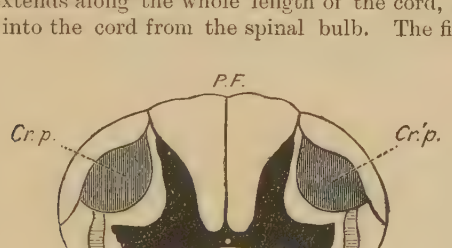


FIG. 156.—DIAGRAM TO SHOW THE POSITION OF TRACTS OF DESCENDING DEGENERATION IN THE WHITE MATTER OF THE SPINAL CORD AT THE SAME LEVEL AS IN FIG. 155.

Cr.p., *Cr'.p'.* crossed pyramidal tracts; *D.'p.'*, *D.p.* direct pyramidal tracts; *desc. a.l. desc. a.l.* descending antero-lateral tract.

this tract are believed to join on to those cells in the anterior horns of the grey matter whose process, as previously described (p. 463), gives rise to the nerve fibres which leave the cord as the efferent (motor) anterior roots of the spinal nerves. It may thus be regarded as the path for efferent impulses coming down the cord on their way to outlying parts of the body.

But this tract, unlike those we have so far described, does not end, or rather we should now say begin, in the spinal bulb. On the contrary, it may be traced up through

the bulb into the higher parts of the brain and is found to start from a certain portion of what we shall describe later on as the **cortex of the cerebral hemispheres.** It is upon the cells of this part of the cortex that the fibres of the pyramidal tracts depend for their nutrition; hence injury to this portion of the cortex leads to a degeneration which extends right down to the lowest end of spinal cord. These facts still further confirm the idea that this tract provides a path for efferent (motor) impulses in the cord, since, as we shall see, that part of the cerebral cortex of which we are now speaking, is specially concerned in the development of efferent (motor) impulses.

The fibres of this tract which enter the spinal bulb from, say, the **left** side of the brain, cross over in the bulb, in what is known as the *decussation of the pyramids* (p. 515) just above the origin of the first cervical nerve, and then pass down the **right** side of the spinal cord. For this reason it receives the name of the "crossed" pyramidal tract.

(ii) **The Direct Pyramidal Tract.**—This is a small tract in the median part of the anterior white columns, adjacent to the anterior fissure. (Fig. 156, *D'.p'.*, *d.p.*). It really consists of a small portion of those fibres which passed into the bulb as the main pyramidal tract coming from the cortex of the cerebral hemispheres, but which have *not crossed over* in the bulb. Thus in Fig. 156 the direct tract *D.p.* comes from the same side of the brain as the crossed pyramidal tract *Cr.p.*, and a similiar remark applies to *D'.p'.* and *Cr'.p.*

(iii) **The Descending Antero-lateral Tract.**—This tract is not very clearly marked; our knowledge of it is very imperfect and it is mentioned here merely for the sake of completeness (Fig. 156, *desc.a.l.*, *desc.a.l.*).

Such are the functions of the spinal cord, taken as a whole. The *spinal* nerves are, as we have said, chiefly

stributed to the muscles and to the skin. But other rves, such as those for instance belonging to the blood-ssels, the so-called *vaso-motor* nerves (Lesson II. p. 71), ough many of them run for long distances in the sym-thetic system, may ultimately be traced to the spinal rd. Along the spinal column the spinal nerves give off nches which run into and join the sympathetic system. nd the vaso-motor fibres which run along in the sym-thetic nerves do really spring from the spinal cord, ding their way into the sympathetic system through ese communicating or commissural branches. Besides hich, some vaso-motor fibres run in spinal nerves along eir whole course.

Experiments moreover go to show that the nervous in-ences which, through these vaso-motor nerves, regulate e blood-vessels, now forcibly constricting them, now lowing them to dilate, and now keeping them in a state moderate or tonic constriction, proceed from the spinal rd.

The cord is, therefore, spoken of as containing *centres* r the vaso-motor nerves or, more shortly, *vaso-motor ntres.*

For example, the muscular walls of the blood-vessels pplying the ear and the skin of the head generally, are ade to contract, as has been already mentioned, by rvous fibres derived immediately from the sympathetic. hese fibres, however, do not arise from the sympathetic nglia, but simply pass through them on their way from e spinal cord, to the upper dorsal region of which they n all be traced. At least, this is the conclusion drawn om the facts, that irritation of this region of the cord oduces the same effect as irritation of the vaso-motor rves themselves, and that destruction of this part of e cord paralyses them.

It has, however, been further shown that the nervous fluence does not originate here, but proceeds from gher up, from the medulla oblongata in fact, and simply

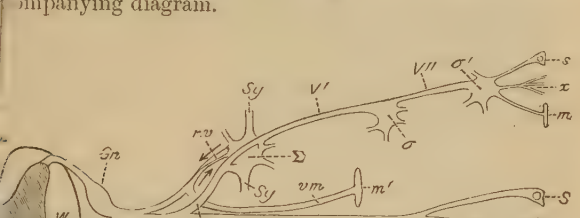
passes down through this part of the spinal cord on its way to join the sympathetic nerves.

9. The Sympathetic Nervous System.—The sympathetic system consists chiefly of a double chain of ganglia lying at the sides and in front of the spinal column, and connected with one another, and with the spinal nerves, by commissural cords (Fig. 142). From these ganglia, nerves are given off which for the most part follow the distribution of the blood-vessels, but which, in the thorax and abdomen, form great networks, or *plexuses*, upon the heart and about the stomach and other abdominal viscera. A great number of the fibres of the sympathetic system are derived from the spinal cord; but others originate in the ganglia of the sympathetic itself, of which some run back into the spinal nerves for distribution to the blood-vessels of the limbs.

By means of the sympathetic nerves the muscles of the vessels generally, and those of the heart, of the intestines, and of some other viscera may, as we have seen, be influenced; and the influence thus conveyed, it may be remarked, is generally different to, or even antagonistic to that which is conveyed to the same organs by the fibres running in the spinal or cranial nerves. Thus while irritation of the (cranial) pneumogastric fibres stops the heart, irritation of the sympathetic fibres going to the heart increases the beat.

But the influences which thus reach these organs through the sympathetic nerves, do not originate in the sympathetic system itself, but are derived from the spinal cord or brain. We have seen (p. 71) this to be the case in reference to vaso-motor nerves, and the same is true of the sympathetic nerves going to the heart and other viscera. Whatever may turn out to be the function of the sympathetic ganglia, there is at present no adequate evidence that they in any way act as nervous centres either of reflex action, or of any other form of nervous activity. Hence the sympathetic is not to be regarded a

separate nervous system, but as being in reality merely outlying part of the cerebro spinal system, an outlying in of ganglia, through which the fibres of a part of trunk of each spinal nerve pass on their way to the cera. This relationship is made quite clear by the ompanying diagram.



. 157.—Diagram to illustrate the Distribution of the Spinal Nerves and their Relationship to the Ganglia of the Sympathetic System.

F, anterior fissure; *P.F*, posterior fissure; *Gr*, grey matter, *W*, white tter of spinal cord; *A*, anterior root of spinal nerve; *Gn*, ganglion on posterior root; *N*, the trunk of a spinal nerve; *N'*, spinal nerve per, ending in a skeletal muscle *M*, in a sensory cell or surface *S*, or other ways *X*; *V*, a branch (white ramus communicans) of the spinal ves passing to Σ a ganglion of the sympathetic system, then passing as *V'* to some more distant ganglion σ, and then as *V''* to some peri-eral ganglion σ', and ending in a muscle *m* of the blood-vessels or cera, in *s* an internal (visceral) sensory cell or surface, or in other ys *x*.

rom Σ a nerve *r.v.* (grey ramus communicans) runs back and passes tly towards the spinal cord and partly, as vaso-motor fibres *r.m.*, in nection with the spinal nerve *N'*, to *m'* the muscles of blood-vessels certain parts *e.g.* of the limbs.

y, *Sy*, the main chain of the sympathetic system which unites the eral ganglia Σ of that system. (See Fig. 142.)

The fibres which make up the essential structure of the ves with which we have so far dealt were spoken of as *dullated*, because except at their peripheral and central minations they possess the characteristic medulla 456). But scattered among these medullated fibres are few which are often spoken of as *non-medullated*,

because they possess no medulla. These non-medullated fibres are peculiarly abundant in the nerves of the sympathetic system, so much so that they are frequently called "sympathetic fibres." They appear under the microscope as pale flattened bands, about as wide as small medullated fibres, often fibrillated longitudinally, and frequently dividing. They appear, in fact, to be naked neuraxes (axis-cylinders), without medulla, and apparently without a neurilemma, though they bear at intervals on their surface nuclei which may represent the internodal nuclei of ordinary nerve fibres.

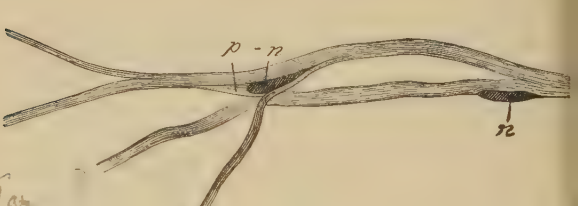


FIG. 158.—PALE NON-MEDULLATED FIBRES FROM THE PNEUMOGASTRIC NERVE. (RANVIER.)

n, nucleus; *p*, protoplasm belonging to the nucleus.

The ganglia of the sympathetic system are composed of nerve cells bound together by a small amount of loose connective tissue. The cells differ somewhat in appearance and arrangement according to the ganglion in which they are seen, but speaking broadly and generally they may be said to resemble in their most obvious features the motor cells of the spinal cord, whose structure we have previously described (p. 462). Like the latter, each nerve cell of a sympathetic ganglion contains a large and conspicuous nucleus, and the cell-body is prolonged into a varying but usually large number of branching processes (dendrites). Moreover, each cell

sesses one process which does not branch but passes ay from the body of the cell as a (usually) *non-dullated* nerve fibre, to be distributed to the various ues (p. 490) which it influences, and is in this respect lar to the axis-cylinder process of a cell of the spinal d. Each ganglion is also connected with nerve fibres ch come to it from the central nervous system (Fig.). These fibres mostly end in connections with the ve cells. Sometimes a fibre does not end in the first nglion it meets, but passes right through it into one the nerves going off from that ganglion, and so reaches me other more distant ganglion. The number of ve fibres which thus pass into the ganglion from the nal cord is much less than the number of nerve cells the ganglion; hence many more nerve fibres are found ming from the ganglion than entering it. By this rangement each ganglion provides, as it were, a sort of nction by means of which any nervous impulses which ch it along any one path may be the more readily and dely distributed, along several paths, to the tissues.

10. **The Structural Arrangements of the Brain and inal Bulb (Medulla Oblongata).**—The brain is a very mplex organ consisting of many parts. It occupies the vity of the skull and is thus placed at the upper end of e spinal cord with which it becomes connected by means the spinal bulb[1]; this passes insensibly into, and in its wer part has the same structure as, the spinal cord. hen viewed from the side, after the removal of the parts ich cover in the cerebro-spinal system, the brain pre-nts the appearance shown in the following figure. The inal cord (*N*) widens out into the bulb (*M.Ob.*) whose per end passes on into the large *convoluted* structure *.C.C.*) which is called the (right) **cerebral hemisphere.** ing beneath the hinder end of the hemisphere is a ge laminated mass which overhangs the posterior side

Throughout this section we shall use the word "bulb" in shortness spinal bulb, and instead of the older name "medulla oblongata."

of the bulb and is known as the **cerebellum** (*Cb.*). When the brain is removed from the skull and looked at from

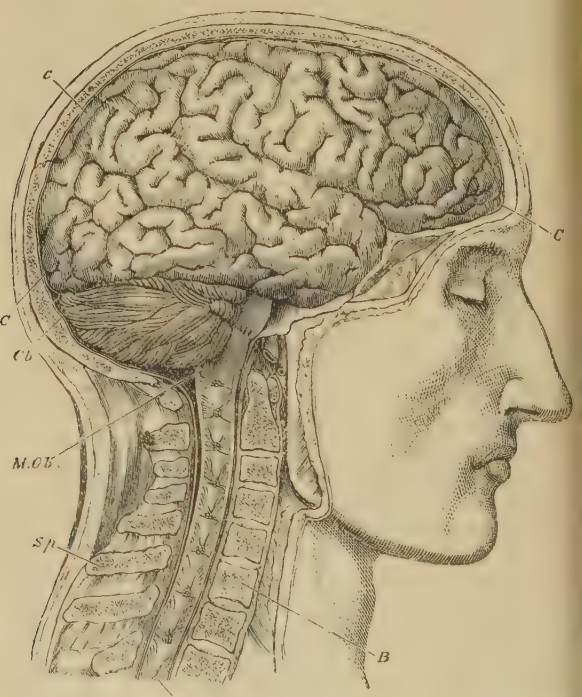


FIG. 159.—SIDE VIEW OF THE BRAIN AND UPPER PART OF THE SPINAL CORD IN PLACE—THE PARTS WHICH COVER THE CEREBRO-SPINAL CENTRES BEING REMOVED.

C. C. the convoluted surface of the right cerebral hemisphere; *Cb.* the cerebellum; *M.Ob.* the medulla oblongata; *B.* the bodies of the cervical vertebræ; *Sp.* their spines; *N.* the spinal cord with the spinal nerves.

its base or under surface many further details may be at once made out. Thus it becomes evident that the

ain consists of two halves, corresponding to each half of
e spinal cord, lying symmetrically on each side of a line
ning *CC.* and *M.* in Fig. 160. The bulb (*M*) widens out
its upper end and gives off from each side a number of
ves (vii.—xii.) which are analogous to the spinal nerves
as originating from the brain, are called **cranial**
rves. The other six pairs of cranial nerves (i.—vi.)
e off from parts of the brain in front of (above) the
b. The cerebellum is seen to send out from each side
ards the central line a large mass of transverse fibres
ch sweep across the brain and meet, with a depression
he middle line, thus forming a sort of bridge from one
of the cerebellum to the other ; this bridge lies just in
t of (above) the bulb and is called the **pons Varolii.**
number VI. is placed upon the *pons* in Fig. 160. The
gitudinal nerve fibres of the bulb pass forwards
wards in the figure), among and between the transverse
es of the *pons*, and become visible again in front of it
two broad diverging bundles called **crura cerebri,**
ch plunge into the corresponding **cerebral hemi-**
here of each half of the brain.

When the brain is viewed from above nothing is visible
ond the convoluted surfaces of the two cerebral hemi-
eres, separated by a median fissure whose sides are in
se contact. But if the sides of this fissure are carefully
hed apart, the cerebral hemispheres may be seen to be
nected with each other by an elongated transverse and
izontal mass of nerve fibres known as the **corpus**
llosum (shown as *CC.*, in Fig. 160). If the hinder
ds of the cerebral hemispheres are raised, the whole
per surface of the cerebellum comes into view, and if
cerebellum is now lifted up, the *posterior* surface of
bulb is exposed. Unlike the anterior surface, which
onspicuously convex (see Fig. 160, *M*) the posterior
face is marked by a shallow elongated diamond-shaped
ression, forming the cavity of the **fourth ventricle.**
is cavity arises from the gradual divergence of the

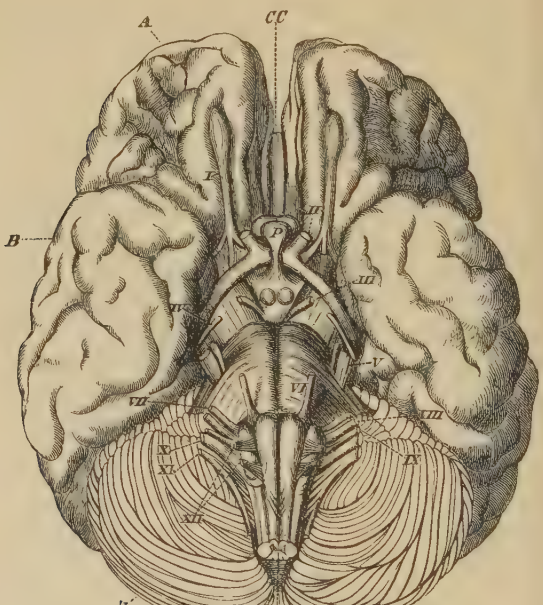


FIG. 160.—THE BASE OR UNDER-SURFACE OF THE BRAIN.

A, frontal lobe; *B*, temporal lobe of the cerebral hemispheres; *Cb* cerebellum; *I*, the olfactory nerve; *II*, the optic nerve; *III*, *IV*, *VI*, the nerves of the muscles of the eye; *V*, the trigeminal nerve; *VII*, the facial nerve; *VIII*, the auditory nerve; *IX*, the glossopharyngeal *X*, the pneumogastric; *XI*, the spinal accessory; *XII*, the hypoglossal or motor nerve of the tongue. The number *VI* is placed upon the *pons Varolii*. The *crura cerebri* are the broad bundle of fibres which lie between the third and the fourth nerves on each side. The medulla oblongata (*M*) is seen to be really a continuation of the spinal cord; on the lower end are seen the two crescents of grey matter; the section, in fact, has been carried through the spinal cord, a little below the proper medulla oblongata. From the sides of the medulla oblongata are seen coming off the *X*, *XI*, and *XII* nerves; and just where the medulla is covered, so to speak, by the tranversely disposed *pons Varolii*, are seen coming off the *VII* nerve, and more towards the middle line the *VI*. Out of the substance of the *pons* springs the *V* nerve. In front of that is seen the well-defined anterior border of the *pons*; and coming forward

sterior white columns of the spinal cord, while the oth of the posterior fissure is at the same time dimin- ed, so that the central canal of the spinal cord proaches the floor of the fourth ventricle, and actually ens into the lower end of the cavity (Fig. 161); this er end of the ventricle is known as the **calamus riptorius**, from its fancied resemblance in shape to e nib of a pen. The narrowed upper end of the fourth ntricle is continued forwards under the cerebellum.

Having thus made out so much of the arrangement of the n as may be seen by mere external inspection, we may w proceed to examine its internal structure. For this rpose the most instructive method is to cut a vertical, gitudinal section through the brain from front to back, ssing through the middle line, and thus dividing it into o similar and symmetrical halves. When the cut face of the right half of the brain, as exposed by this tion, is examined, the following further structural tails may be made out, and are shown in Fig. 161.

The *corpus callosum* is seen *cut* across at *cc. cc. cc.* Above is, and extending forwards and backwards, is the flattened *posed surface* of the right cerebral hemisphere, which ms one side of the median fissure between the hemis- eres. The upper end of the spinal cord, *Sp.c.*, passes o the bulb *B*, in front of which the transverse fibres the *pons* are seen in section at P, while the longitudinal res of the bulb run forward above the pons to emerge front as one of the (right) *crura cerebri*. Anteriorly is crus disappears out of the section since it diverges to

front of that line, between the *IV* and *III* nerves on either side, are n the *crura cerebri*. The two round bodies in the angle between the erging crura are the so-called *corpora albicantia*, and in front of them ?, the pituitary body. This rests on the chiasma, or junction, of the ic nerves; the continuation of each nerve is seen sweeping round the ra cerebri on either side. Immediately in front, between the separ- d frontal lobes of the cerebral hemispheres, is seen the *corpus osum, CC.* The fissure of Sylvius, about on a level with *I* on the left *II* on the right side, marks the division between frontal and nporal lobes.

the right (see Fig. 160) from the median line of the brain to enter the corresponding cerebral hemisphere. The cerebellum *Cb*, is seen *in section* overhanging the bulb, and between it and the bulb is the cavity, shaded and marked

FIG. 161. VIEW OF THE RIGHT HALF OF A HUMAN BRAIN AS SHOWN BY A LONGITUDINAL SECTION IN THE MEDIAN LINE THROUGH THE LONGITUDINAL FISSURE. (AFTER SHERRINGTON.)

Sp.c. spinal cord; *B*, bulb; *P*, pons; *CR*, *crus cerebri*; *M*, *corpus albicans*; *Cb*, cerebellum; *c.c*, central canal of spinal cord opening into 4 the fourth ventricle; *V.V*, valve of Vieussens; *QP*, *QA*, *corpora quadrigemina*, beneath which is the *aqueduct of Sylvius* leading from the fourth ventricle into 3, the cavity of the third ventricle; *P*, pineal gland; *F*, fornix or roof of third ventricle; *OT*, *optic thalamus*; *H*, pituitary body; *OP*, optic nerve cut across at the optic decussation (see Figs. 160 and 167); *SL*, a part of the *septum lucidum*, of which the remainder has been cut away to reveal *NC*, *LV*, the cavity of the lateral ventricle; this communicates with the third ventricle by means of the *foramen of Monro*, whose position is marked by a small *x* at the front end of the third ventricle; *cc,cc,cc*, *corpus callosum*, above which is the mesial surface of the right cerebral hemisphere.

with a 4, to which we have previously alluded as the *fourth ventricle*. The central canal *c.c.* of the spinal cord is shown as an opening into the hinder end of the cavity of the fourth ventricle, while the front end of the cavity is prolonged into a narrow passage, the aqueduct o

ylvius, which leads into a much larger cavity nown as the **third ventricle**, and marked by a 3. bove this aqueduct are *four* largely developed masses of ssue, but of these *two* only are seen in the section at *QA*, *P*, since the four are arranged in two pairs, one pair ing placed each side of the middle line of the brain; m their number (four) these structures have received e name of **corpora quadrigemina**. In front of the rpora quadrigemina is a small structure, seen in section, e **pineal gland**, *P*. The posterior corpus quadri- minum is continuous with a thin layer of nervous ssue, which leads back into the cerebellum; this rms an overhanging roof to the front end of the fourth ntricle, and is known as the **valve of Vieussens** ig. 161, *v.v.*). The floor of the third ventricle is oduced forwards and downwards into a funnel-shaped ace, to the tip of which is attached a body of a glandular ture known as the pituitary body (Fig. 160, *P*, and g. 161, *H*). The roof of the third ventricle is provided a layer of tissue seen *in section* and known as the rnix (Fig. 161, *F*); this is connected posteriorly with e hinder end of the *corpus callosum*, and in front it rves downwards and backwards into the lateral wall of the ird ventricle towards the **corpus albicans**, *M*. The *tical* space between the fornix and the corpus callosum is led in by a thin *double* layer of nervous tissue; this is nown as the **septum lucidum**. It lies in the plane of e paper on which the figure is printed, but only a small rtion of it is shown at *SL*. The remaining part has been t away in order to reveal a feature of which, so far, no ention has been made, viz., the darkly shaded cavity *NC.*, *V.*, lying in the middle of the cerebral hemisphere, and nown as the (right) **lateral ventricle**. The cavity of is ventricle communicates with that of the third ventricle a small opening at *x*, the **foramen of Monro**. Since e septum lucidum consists of two layers there is a small ttened closed space between these layers in the middle

line of the brain ; this is spoken of as the **fifth ventricle**, but it has no actual connection with the other ventricles.[1] (See Fig. 163, 5.) Each lateral ventricle is a cavity of a very peculiar shape, one branch running forwards towards the front end of the hemisphere and one backwards towards the hinder end, and from the latter a third branch runs downwards and once more forwards. These correspond respectively to the chief **lobes** of which each hemisphere is made up, namely the **frontal** lobe, the **parietal** and

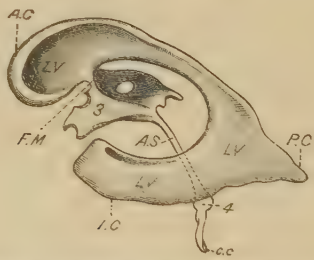


FIG. 162. DIAGRAM TO SHOW THE SHAPE OF THE CAVITY OF THE LEFT LATERAL VENTRICLE, ITS CONNECTION WITH THE THIRD VENTRICLE, AND THE CONNECTION OF THE LATTER WITH THE FOURTH VENTRICLE, AND HENCE WITH THE CENTRAL CANAL OF THE SPINAL CORD.

Drawn from a *cast* of the ventricles. (After Welcker.)

c.c. canal of spinal cord ; 4, fourth ventricle ; *A.S.* aqueduct of Sylvius ; 3, third ventricle ; *F.M.* foramen of Monro ; *LV*, *LV*, *LV*, lateral ventricle with its anterior cornu, *A.C.*, posterior cornu, *P.C.*, and inferior cornu, *I.C.*

occipital lobes, and the **temporal** lobe. These lobes are marked off on the surface of the hemispheres by **fissures**, of which the most conspicuous are the **fissure of Sylvius**, and the **fissure of Rolando.** (See Fig. 168).

The cerebellum is firmly connected to the rest of the brain by the transverse fibres which help to form the

[1] The two lateral ventricles, one in each cerebral hemisphere, are reckoned as the first and second ventricles ; hence the space between the layers of the septum lucidum is known as the fifth ventricle.

ons Varolii (Fig. 160), and constitute the **middle peduncle** of each half of the cerebellum. But each alf has a further attachment by means of two other ands of fibres. Of these one coming out of the central nedullary) part of the cerebellum on each side, runs rwards towards, and disappears under, the corpora uadrigemina; this forms the **superior peduncle.** he other runs backwards towards the bulb and merges, s the **inferior peduncle,** into that part of the bulb hich is a continuation upwards of the lateral columns of hite matter of the spinal cord.

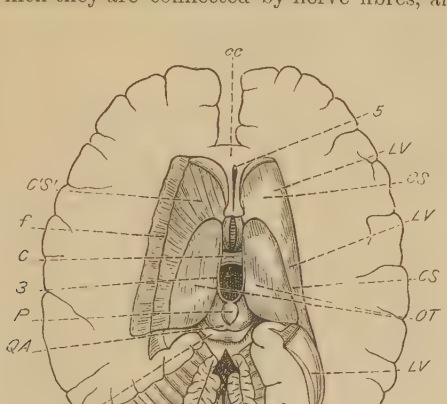
We have seen that the spinal cord consists essentially a central canal surrounded by grey matter containing erve cells, external to which is a covering of white natter composed of nerve fibres; and the arrangement of ne grey and white matter is comparatively simple. Now om the description we have so far given of the brain, it evident that the brain may also be regarded as being uilt up of structures which are placed round the sides of central canal, which is really continuous with the canal the spinal cord. But, unlike the latter, the canal of he brain, consisting of the ventricles and aqueduct, is not simple straight tube, but has a very peculiar shape. Moreover, although the brain is made up of grey and hite matters, which by their greater or less development rm the structures of varying size which make up the rain as a whole, the grey and white matters are not arnged in any simple way as they are in the spinal cord. n the contrary, although in the brain a great deal f the grey matter is placed externally to the hite, the latter is interspersed with localised deosits of grey matter, some large, some small, which give o the whole an extraordinary complexity. And this mplexity is still further increased by the existence of rands or bundles of nerve fibres, which serve to interonnect all these various deposits of grey matter, so as to nsure the possibility of co-ordinated action between each

individual part of which the brain as a whole is built up. It would be neither possible nor desirable to attempt to deal in any detail in this book with the varied arrangements of the several deposits of grey matter in the brain, and with their connections by strands of white matter. But some of them stand out so conspicuously as structures, and are so important in their functions, that we must of necessity take them into consideration.

The Corpora Quadrigemina.—These have already been described as four conspicuous masses of tissue lying in two pairs above the aqueduct of Sylvius. They consist of deposits of grey matter in the otherwise thin wall of the roof of the aqueduct. Each deposit is surrounded by white matter, and from each bands of fibres run obliquely downwards and forwards, those from the anterior pair of the corpora making connection with structures connected with the optic nerve (Fig. 160, *II.*), while those from the posterior pair are believed to make similar connections with the nerves concerned in hearing (Fig. 160, *VIII.*).

The Optic Thalami.—The longitudinal fibres of the bulb, passing between the transverse fibres of the pons reappear, as we have seen, in front of the pons as the *crura cerebri*. These diverge from the middle line to enter the cerebral hemispheres. As each crus passes into the base of the corresponding hemisphere, it receives on its *upper* surface a large deposit of grey matter placed somewhat obliquely across its course; this mass of grey matter is the **optic thalamus**. Lying thus to one side of the third ventricle, and under the lateral ventricle, it is easily seen how each optic thalamus comes to form a projection in the outer side-wall of the third ventricle, and on the floor of the lateral ventricle. Thus the optic thalamus is shown at *O.T.* in Fig. 161, as part of the wall of the third ventricle, and as *O.T.* in Fig. 163, which represents in diagram a *horizontal* section through the hemispheres passing above the floor of the lateral

entricles. The inner sides of the optic thalami are nnected by a small commissure (Fig. 163, *C.*), which xtends across the third ventricle ; their outer sides are bedded in the substance of the cerebral hemispheres ith which they are connected by nerve fibres, and from



G. 163.—Diagram of a Horizontal Section of the Brain above the loor of the Lateral Ventricles. (After Hirschfeld and Leveillé.)

Sp.c. spinal cord ; *B*, bulb ; *Cb*, *Cb*, cerebellum ; 4, fourth ventricle ; *P.*, *Q.A*, corpora quadrigemina ; *P*, pineal gland ; 3, third ventricle ; fifth ventricle ; *cc*, front part of corpus callosum ; *LV*, *LV*, *LV*, lateral ntricle ; *OT.*, optic thalami ; *CS*, *CS*, corpus striatum ; *C*, commissure of optic thalami. On the left side *CS* marks the corpus riatum, into which an incision has been made and a flap, *f*, turned ck to show its internal striated appearance.

eir hinder end a bundle of fibres sweeps forward to ass into the tract of the optic nerves.

The Corpora Striata. Each corpus striatum may be garded as a mass of grey matter deposited obliquely, as as each optic thalamus, on the course of the crura

cerebri, but lying somewhat in front of the optic thalami. Hence the corpora striata are seen as a projection on the floor of the lateral ventricles (Fig. 163, *C.S.*, *C.S.*), and as part of the side wall of the front end of this ventricle (Fig. 161, *NC.*). Each corpus consists of two parts, one lying in front of the optic thalamus, the other further back and by the side of the thalamus. The larger part of each corpus striatum is imbedded in the neighbouring substance of the cerebral hemisphere, with which it is intimately connected by nerve fibres. It is also similarly connected with the fibres of the crus on which it lies.

A clear understanding of the position and relations of the optic thalami and corpora striata is essential in connection with the course of a tract of nerve fibres with which we shall deal later, known as the **internal capsule.**

The Membranes of the Brain.—The brain is invested by three membranes which are the same in name, and similarly placed and related to each other as those which we have previously described as covering the spinal cord (see p. 448). Of these the pia mater is highly vascular, and carries blood-vessels down into the grey matter, especially in the **sulci** or grooves to which the convoluted appearance of the surface of the brain is due. Moreover, it forms a roof to the hinder part of the cavity of the fourth ventricle, and a highly developed layer of the pia mater is tucked in under the hinder end of the cerebral hemispheres to form the roof of the third ventricle; this is known as the **velum interpositum.** The edges of this velum as it lies beneath the *fornix* project on each side into the cavities of the lateral ventricles and are here known as the **choroid plexuses**, the whole being arranged with a view to the nutrition of the internal parts of the brain. The cavities of the cerebral ventricles, and hence of the central canal of the spinal cord, are placed in communication with the *subarachnoid space*, by

small opening in the pia mater covering the hinder end of the fourth ventricle; this opening is known as the foramen of Magendie.

11. The Minute Structure of the Brain.—In the spinal bulb the arrangement of the white and grey matter is substantially similar to that which obtains in the spinal cord, that is to say, the white matter is external and the grey internal; but the grey matter, containing, as in the spinal cord, nerve cells, is more abundant than in the spinal cord, and the arrangements of white and grey matter become much more intricate and complex. The structure of the white matter of the brain is essentially the same as that of the spinal cord.

Above the bulb there are internal deposits of grey matter, containing nerve cells, at various places, more especially in the pons Varolii, the crura cerebri, the corpora quadrigemina, optic thalami and corpora striata. And there is a remarkably shaped deposit of grey matter in the interior of the cerebellum, on each side. But what especially characterises the brain is the presence of grey matter of a special nature, containing peculiarly shaped nerve cells, on the surface of the cerebral hemispheres known as the **cortex**, and similarly a special grey matter forms the surface of the cerebellum. This superficial grey matter covers the whole surface of both these organs, dipping down into the fissures (sulci) of the former, and following the peculiar plaits or folds into which the latter is thrown.

The Cerebellum.—The surface of the cerebellum presents a corrugated or laminated appearance. When a section is made through one of its hemispheres it is seen that the depressions which separate the laminæ give off secondary lateral depressions as they pass towards its centre, so that the surface is really divided up into a very large number of leaf-like foldings which are known as the **folia**. The central part of the cerebellum consists of white matter which is essentially the same as the white

matter of the spinal cord, that is to say, it is made up chiefly of medullated nerve fibres. Portions of this white matter extend outwards into the primary foldings and secondary lamellæ of the cerebellar surface, and are covered by grey matter, the arrangement thus presenting a very characteristic arborescent appearance when seen in section.[1]

When a section of the external grey matter is cut at right angles to the surface of a lamella, stained, and examined under the microscope, it is found to consist of two layers. The innermost, lying next to the central white matter, is made up of a large number of small closely-packed cells supported by neuroglia (see p. 460) and is known as the **nuclear layer** (Fig. 164, *N*). The outer layer, immediately under the pia mater, shows a few cells, but the chief appearance it presents is that of a granular mass made up of closely-set dots. These dots are in reality the cut ends of fibres of which some belong to the supporting neuroglia, but of which the majority are nerve fibrils. From its punctated appearance (Fig. 164, *x*.) this layer, which is much broader than the nuclear layer, is known as the **molecular layer** (Fig. 164, *M*.). Between these two layers lies a row of nerve cells of very striking and characteristic appearance, known as the **cells of Purkinjé** (Fig. 164, 1). These are pear-shaped, with a large and conspicuous nucleus, the bulbous inner end resting on the nuclear layer, while the outer end divides into a large number of processes which run out into the molecular layer as finer and finer branches. The granular appearance of the molecular layer is in part due to the close juxtaposition of the cut ends of these branches or *dendrites* from the cells of Purkinjé. The inner end of each cell bears a single process which is usually cut through near the cell but is really prolonged down into the central white matter as a medullated nerve fibre. Such are the details which can be made out

[1] This is somewhat imperfectly shown in Figs. 161 and 163.

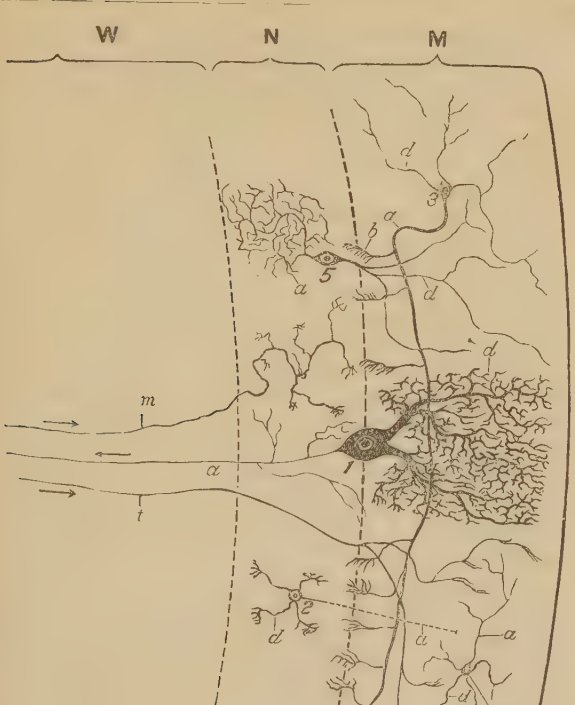


FIG. 164.—DIAGRAM TO ILLUSTRATE THE STRUCTURE OF THE SUPERFICIAL GREY MATTER OF THE CEREBELLUM AS SEEN IN A TRANSVERSE SECTION OF A LAMELLA.

M, molecular layer; *N*, nuclear layer; *W*, central white matter; 1, cell of Purkinjé; 2, spider-cell; 5, cell of Golgi; 3, basket-cell with one of its baskets, *b*; 4, another kind of cell in the molecular layer; *t*, tendril fibre; *m*, moss-fibre.

In the case of each cell *a* is the axon or main undivided process, *d* is a dendrite or divided process.

in an ordinarily stained section. But by employing special methods of staining many further details come into view, and putting all these together we are justified in constructing the preceding diagrammatic Figure 164 to show the nature and relationships of the cells of the cerebellar cortex and of its two layers to the fibres of the central white matter.

In this figure the cells which call for special attention are the following. The cell of Purkinjé (1) with its central axon (*a*) and peripheral dendrites (*d*). The basket-cell (3) with its axon (*a*) and baskets (*b*) : the baskets in reality surround the bodies of cells of Purkinjé which, for the sake of clearness are not shown in the diagram. The spider-cell (2) in the nuclear layer with its axon (*a*) running into the molecular layer and dendrites (*d*). Also in addition to the fibre derived from the inner end of the cell of Purkinjé it is important to notice the moss-fibre (*m*) whose outer end terminates by branching in the nuclear layer and the tendril-fibre (*t*) which passes further outwards but ends similarly in the molecular layer. The direction in which impulses are supposed to travel along these fibres is indicated by arrows.

The Cerebral Cortex.—The structure of the superficial grey matter of the cerebellum is practically the same in each part of the cerebellar cortex. In the cerebrum, on the other hand, the details of structure vary not inconsiderably according to the region of the cortex from which a section is prepared. Into these differences we cannot enter, but must content ourselves with a somewhat diagrammatic description and figure in illustration of the general structural arrangement of the cells and fibres of the cortex as a whole.

The grey matter is permeated throughout its whole thickness by a neuroglia which is essentially the same as that of the rest of the central nervous system. This forms the supporting tissue in which the nerve cells of the cortex are imbedded and through

FIG. 165.—DIAGRAMMATIC FIGURE TO ILLUSTRATE THE STRUCTURE OF A TYPICAL SECTION OF THE CEREBRAL CORTEX.

I. Molecular layer. *II.* Layer of pyramidal cells. *III.* Layer of polymorphous cells.

c and *c'*, cells of the molecular layer; *p'*, *p''*, *p'''*, pyramidal cells; *p*, cell of the polymorphous layer; *m.r.* medullary ray of nerve fibrils from central white matter; *x*, *y*, *z*, tangential bundles of nerve fibrils.

which the fibrils of nerves pass to and from these cells from the central white matter. The latter is composed, as in the cerebellum, of medullated nerve fibres. This neuroglia is most marked in the outermost parts of the cortex, immediately below the pia mater, and since in a section its wavy fibres are mostly seen as sectional dots, this layer of the cortex is known as the **molecular layer** (Fig. 165, *I*). Internally to this layer the cortex is characterised by the presence of nerve cells whose shape is pyramidal with the apex of each cell pointed towards the surface of the brain. This layer may therefore be spoken of as the **layer of pyramidal cells** (Fig. 165, *II*). These cells vary in size in the several parts of this layer, the largest being found in the inner portion, the smallest next to the molecular layer. That part of the cortex which lies immediately external to the central white matter is characterised by the presence of nerve cells of a somewhat irregular form, hence this layer is known as the **layer of polymorphous cells** (Fig. 165, *III*).

In addition to the nerve cells and their processes which characterise the several layers of the cortex, nerve fibrils pass up into and through the cortex from the central white matter. Of these some are arranged in bundles at right angles to the surface of the cortex, **medullary rays** (Fig. 165, *m.r.*) while others lie parallel to the surface as **tangential rays** (Fig. 165, *x.y.z.*).

12. **The Cranial Nerves.**—Nerves are given off from the brain in pairs, which succeed one another from before backwards, to the number of twelve (Figs. 160 and 166). These are often called "*cranial*" nerves, to distinguish them from the spinal nerves.

The *first pair*, counting from before backwards, are the **olfactory nerves**, and the *second* are the **optic nerves**. The functions of these have already been described. But these two nerves require special notice. That which is commonly called the olfactory "nerve" is really a lobe

of the brain and contains nerve cells. The proper olfactory nerves are bundles of fibres which proceed from the under surface of the above and traverse the cribriform plate to be distributed to the olfactory mucous membrane. And it is an extremely remarkable fact that these fibres closely resemble the non-medullated fibres of the sympathetic nerves, in being hardly anything more than neuraxes, bearing nuclei at intervals. A sheath, apparently representing the neurilemma, is however present in each fibre.

The optic "nerve" is also properly speaking a lobe of the brain, and it retains its character as a part of the central nervous system in so far as its fibres have no neurilemma and are nodeless, but it contains no nerve cells along its course.

The *third pair* are called **motor oculi** (mover of the eye), because they are distributed to all the muscles of the eye except two.

The nerves of the *fourth pair*, **trochlear**, and of the *sixth pair*, **abducens**, supply, each, one of the muscles of the eye, on each side; the fourth going to the **superior oblique muscle**, and the sixth to the **external rectus**. Thus the muscles of the eye, small and close together as they are, receive their nervous stimulus by three distinct nerves.

Each nerve of the *fifth pair* is very large. It has two roots, a motor and a sensory, and further resembles a spinal nerve in having a ganglion on its sensory root. It is the nerve which supplies the skin of the face and the muscles of the jaws, and, having three chief divisions, is often called **trigeminal**. One branch containing sensory fibres supplies the fore-part of the mucous membrane of the tongue, and is often spoken of as the *gustatory*.

The *seventh pair* furnish with motor nerves the muscles of the face, and some other muscles, and are called **facial**.

The *eighth pair* are the **auditory** nerves. As the seventh and eighth pairs of nerves leave the cavity of the skull together, they are often, and especially by English writers on anatomy, reckoned as one, divided into *portio dura*, or hard part (the facial); and *portio mollis*, or soft part (the auditory) of the "seventh" pair. The auditory is, as we have seen (p. 366), further divided into the cochlear and vestibular nerve. (See later, p. 518.)

The *ninth pair* in order, the **glossopharyngeal**, are mixed nerves; each being, partly, a nerve of taste, and supplying the hind-part of the mucous membrane of the tongue, and, partly, a motor nerve for the pharyngeal muscles.

The *tenth pair* are the two **pneumogastric** nerves, often called the **vagus**. These very important nerves, and the next pair, are the only cranial nerves which are distributed to regions of the body remote from the head. The pneumogastric supplies the larynx, the lungs, the liver, and the stomach, and branches of it are connected with the heart.

The *eleventh pair* again, called **spinal accessory**, differ widely from all the rest, in arising from the sides of the spinal cord, between the anterior and posterior roots of the dorsal nerves. They run up, gathering fibres as they go, to the medulla oblongata, and then leave the skull by the same aperture as the pneumogastric and glossopharyngeal. They are purely motor nerves, supplying certain muscles of the neck, while the pneumogastric is mainly sensory, or at least afferent. As, on each side, the glossopharyngeal, pneumogastric, and spinal accessory nerves leave the skull together, they are frequently reckoned as one pair, which is then counted as the *eighth*.

The last two nerves, by this method of counting, become the *ninth* pair, but they are really the *twelfth*. They are the motor nerves which supply the muscles of the tongue.

Of these nerves, the two foremost pair do not properly

deserve that name, but are, as we have said, really processes of the brain. The olfactory pair are prolongations of the cerebral hemispheres; the optic pair, of the walls of the third ventricle.

The optic nerve from each eye meets its fellow nerve from the other eye at the base of the brain below the third ventricle. Here they cross each other in what is called

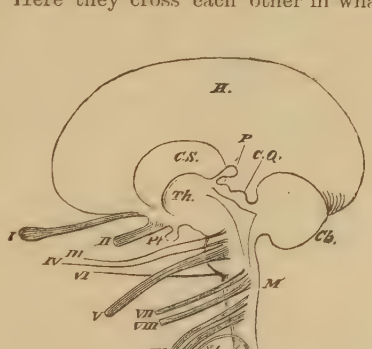


FIG. 166.—A DIAGRAM ILLUSTRATING THE SUPERFICIAL ORIGIN OF THE CRANIAL NERVES.

H. the cerebral hemispheres; *C.S.* corpus striatum; *Th.* optic thalamus; *P.* pineal body; *Pt.* pituitary body; *C.Q.* corpora quadrigemina; *Cb.* cerebellum; *M.* medulla oblongata; *I.—XII.* the pairs of cerebral nerves; *Sp.* 1, *Sp.* 2, the first and second pairs of spinal nerves.

the **optic chiasma** (covered by the pituitary body *P* in Fig. 160) and are continued on backwards, to make connection with the brain, as the **optic tracts**.

These are connected, as already stated, with the hinder part of the optic thalami and with the anterior pair of corpora quadrigemina. At the chiasma the fibres of the optic nerves undergo a remarkable partial decussation. The

fibres from each half of the retina *nearest to the nose cross over to the opposite side of the brain;* the fibres from the other half of each retina pass into the brain without crossing. Hence the right optic tract contains the fibres from the nasal half of the left retina and from the other or temporal half of the right retina, and similarly the left optic tract is made up of the fibres of the temporal half of the left retina and the nasal half of the right retina. This arrangement is essential to the eye as a sense organ with reference to what we have previously spoken of as "corresponding points and single vision with two eyes" (see p. 444).

FIG. 167.—DIAGRAM TO ILLUSTRATE THE DECUSSATION OF FIBRES IN THE OPTIC CHIASMA.

R, right eye; *L*, left eye; *R.Op.* right optic tract; *L.Op.* left optic tract. The decussation is shown by the distribution of the right (shaded) and the left (unshaded) tract to the retinas of the two eyes.

13. The Functions of the Spinal Bulb or Medulla Oblongata.—The bulb plays so important a part in the economy of the body that we may almost enumerate its functions by recalling all the instances in which we have made mention of its activities in the earlier lessons of this book. Thus we have seen that it contains a centre which gives rise to the contractions of the respiratory muscles and keeps the respiratory pump at work, so that injuries to the bulb may arrest the respiratory process (p. 158). Further it contains centres for the regulation of the heart-beat (p. 77) and of the condition of the blood-vessels over the whole body (p. 69). But beyond these the bulb

also contains centres for the nervous act of swallowing, for the reflex secretion of saliva, and for many other actions. Thus we find that simple puncture of one side of the floor of the fourth ventricle produces for a while an increase of the quantity of sugar in the blood, beyond that which can be utilised by the organism. The sugar passes off by the kidneys, and thus this slight injury to the medulla produces a temporary disorder closely resembling the disease called *diabetes*. Hence we speak of a diabetic centre in the bulb. Beyond this the bulb acts as a great conductor of impulses; for all impulses passing up and down between the higher parts of the brain and the spinal cord must make their way through the bulb from or to the spinal nerves. And a similar statement holds good for impulses along the cranial nerves, with the exception of the olfactory, optic and third and fourth nerves.

The impulses which pass through the bulb cross, for the most part, from one side to the other on their way along it. In the case of the *crossed pyramidal tract* the crossing of the fibres which compose the tract takes place by means of what is called the **decussation of the pyramids** in the anterior columns of the bulb (Fig. 172). This point is indicated in Fig. 160 by a group of small converging marks on the surface of the bulb just above the cut end marked *M*. The fibres of the small *direct pyramidal tract* cross below the bulb in the spinal cord by means of its anterior white commissure (see Fig. 143). Similarly the fibres concerned in the transmission of afferent impulses largely cross in the bulb by paths which are varied but of which one is well marked as the **sensory decussation**. This general decussation of efferent and afferent fibres leads to the result that disease or injury of one side of the brain affects the opposite side of the body. Thus when, as not unfrequently happens, a blood-vessel gives way in the right cerebral hemisphere, leading to a destruction of nervous

matter there, the result is that the left arm, and left leg, and left side of the body generally are paralysed, that is, the will has no longer any power to move the muscles of that side, and impulses started in the skin of that side cannot awaken sensations in the brain.

But there is also a decussation of impulses in the case of the nerves arising from the medulla above the decussation of the pyramids. Thus, in the case quoted above of a blood vessel bursting in the right cerebral hemisphere, the left side of the man's face is paralysed as well as the left side of his body, that is to say, impulses cannot pass to and from his brain and the left facial and fifth nerves. The impulses along these nerves also cross over, decussate, and reach the right side of the brain.

It sometimes happens, however, that disease or injury may affect the medulla oblongata itself, on one side only (*e.g.* the right), above the decussation of the pyramids, in such a way that the fifth and facial nerves are affected in their course before they decussate, that is to say, on the same side as the injury. The man then, while still paralysed on the left side of his body, is paralysed on the right side of his face.

14. The Functions of the Cerebellum.—When speaking of reflex actions we pointed out (p. 482) that the complicated movements of walking when once started by the will are essentially reflex in their continued production. Moreover we also drew attention to the fact that the *co-ordination* of the efferent impulses which, although distributed to many different muscles, give rise by their united action to the *orderly* movements of walking, is dependent upon afferent impulses from various parts of the body. Thus walking becomes unsteady or even impossible in the absence of the normal sensory impulses from the skin, or of visual impulses from the eyes; and to these we might have added afferent impulses from the sensory nerves of the muscles themselves. When we take cases of movements which are less obviously reflex,

that is more strictly voluntary, than are those of walking, we find that here again their orderly or co-ordinated production depends largely on tactile and visual impulses. Now experiment and observation in cases of disease have shown quite conclusively that *the one great function of the cerebellum is to play a most important part in the co-ordination of the actions, nervous and muscular, by which the movements of the body are carried on.*

After the cerebellum has been completely removed, an animal does not differ in any essential respect from its normal condition as regards its intelligence or its special senses, such as sight or hearing. But with regard to its movements a great difference is observed in the absence of the cerebellum; all movements are now clumsily executed—there is a want of orderliness or co-ordination. This statement sums up our knowledge of the function of the cerebellum.

We do not know *how* the cerebellum works in thus keeping an orderly grip over the mechanisms of movement; but we see how easily it may do so when we consider its connections with the spinal cord and with the rest of the brain. We saw (p. 486) that two large tracts of afferent fibres from the spinal cord pass into the cerebellum, viz. the *cerebellar tract* by the inferior peduncle and the ascending *antero-lateral tract* by the superior peduncle. Moreover the cerebellum is connected with that part of the bulb in which the *median-posterior tract* ends. Thus it may be a recipient of a vast number of afferent sensory impulses, which are so essential for co-ordinated movement. But each half of the cerebellum is further connected with the cortex of the cerebral hemisphere of the *opposite side* in two ways, firstly, by the fibres of its middle peduncle across the pons Varolii, and secondly, and more directly, by fibres in its superior peduncle (see p. 501). And we shall see that it is exactly in the cortex of the cerebral hemispheres that impulses chiefly arise for the initiation of muscular movements.

When describing the arrangements of the internal ear, it was stated that the semicircular canals have functions other than that of hearing. Now the auditory nerve consists of two quite distinct parts, the *cochlear nerve*, which is distributed to the cochlea, and the *vestibular nerve*, which is distributed to the vestibule, the utricle, saccule, and semicircular canals. These two nerves originate in groups of cells lying in the spinal bulb, and the group of cells which gives rise to the vestibular nerve is directly connected by a strand of fibres with the cerebellum. Thus there is a path by which afferent (sensory) impulses from the semicircular canals may directly reach the cerebellum and there be turned to account in the co-ordination of movements. Bearing this in mind, it is not surprising to find that the semicircular canals, whatever be the part which they play in hearing, play a very important part in the guidance of co-ordinated movement.

The semicircular canals lie in three planes at right angles to each other (p. 366). When any *one* of the canals is experimentally injured, the animal executes a series of oscillatory movements of the head, which are, broadly speaking, in the plane of that canal. When all three canals are injured, the animal is thrown into continuous movements of the most varied and often extraordinary kind, and has lost all power of *balancing* itself in a normal way. Not infrequently in man these canals undergo injury as the result of disease, and in this case the feelings experienced by the patient are those of extreme giddiness, and an inability to balance the body, while the symptoms exhibited to an onlooker are those of a want of co-ordination in the execution of movements. Thus there is no doubt that the semicircular canals, apart from any truly auditory functions they may possess, are of very great importance as organs such that *impulses arising in them enable us to maintain our bodily equilibrium*, and there are reasons for thinking that the utricle and saccule also have a very similar function.

15. The Functions of the Cerebral Hemispheres.—The Hemispheres the Seat of Intelligence and Will.— The functions of most of the parts of the brain which lie in front of the spinal bulb are, at present, very ill understood; but it is certain that extensive injury, or removal, of the cerebral hemispheres puts an end to intelligence and voluntary movement, and leaves the animal in the condition of a machine, working by the reflex action of the remainder of the cerebro-spinal axis.

We have seen that in the frog the movements of the body which the spinal cord alone, in the absence of the whole of the brain, including the bulb, is capable of executing, are of themselves strikingly complex and varied. But none of these movements arise from changes originating within the organism, they are not what are called voluntary or spontaneous movements; they never occur unless the animal be stimulated from without. Removal of the cerebral hemispheres is alone sufficient to deprive the frog of all spontaneous or voluntary movements; but the presence of the bulb and other parts of the brain (such as the corpora quadrigemina, or what corresponds to them in the frog, and the cerebellum) renders the animal master of movements of a far higher nature than when the spinal cord only is left. In the latter case the animal does not breathe when left to itself, lies flat on the table with its fore-limbs beneath it in an unnatural position; when irritated kicks out its legs, and may be thrown into actual convulsions, but never jumps from place to place; when thrown into a basin of water falls to the bottom like a lump of lead, and when placed on its back will remain so, without making any effort to turn over. In the former case the animal sits on the table, resting on its front limbs, in the position natural to a frog; breathes quite naturally; when pricked behind jumps away, often getting over a considerable distance; when thrown into water begins at once to swim, and continues swimming until it finds some object on which it

can rest; and when placed on its back immediately turns over and resumes its natural position. Not only so, but the following very striking experiment may be performed with it. Placed on a small board it remains perfectly motionless so long as the board is horizontal: if, however, the board be gradually tilted up so as to raise the animal's head, directly the board becomes inclined at such an angle as to throw the frog's centre of gravity too much backwards, the creature begins slowly to creep up the board, and, if the board continues to be inclined, will at last reach the edge, upon which when the board becomes vertical he will seat himself with apparent great content. Nevertheless, though his movements when they do occur are extremely well combined and apparently identical with those of a frog possessing the whole of his brain, he never moves spontaneously, and never stirs unless irritated.

Thus the parts of the brain below the cerebral hemispheres constitute a complex nervous machinery for carrying out intricate and orderly movements, in which afferent impulses play an important part, though they do not give rise to clear or permanent affections of consciousness.

There can be no doubt that the cerebral hemispheres are the seat of powers, essential to the production of those phenomena which we term intelligence and will; and there is experimental and other evidence which seems to indicate a connection between particular parts of the surface of the cerebral hemispheres, and particular acts. Thus irritation of particular spots in the anterior part of a dog's brain will give rise to particular movements of this or that limb, or of this or that group of muscles; and the destruction of a certain part of the posterior lobes of the cerebral hemispheres is said to cause blindness. But the exact way in which these effects are brought about is not yet thoroughly understood; and even if it should be ultimately proved beyond all doubt, that the central end-

organ of vision (p. 421) consists of certain nerve-cells lying in a particular part of the posterior surface of the cerebral hemisphere, and that the central end-organ of hearing (p. 386) consists of other nerve-cells lying elsewhere on the cerebral surface, it will still leave us completely in the dark as to what goes on in the cerebral hemispheres when we think and when we will.

There is no doubt that a molecular change in some part of the cerebral substance is an indispensable antecedent to every phenomenon of consciousness. And it is possible that the progress of investigation may enable us to map out the brain according to the psychical relations of its different parts. But supposing we get so far as to be able to prove that the irritation of a particular fragment of cerebral substance gives rise to a particular state of consciousness, the reason of the connection between the molecular disturbance and the psychical phenomenon appears to be out of the reach, not only of our means of investigation, but even of our powers of conception.

Reflex Actions of the Brain. — Even while the cerebral hemispheres are entire, and in full possession of their powers, the brain gives rise to actions which are as completely reflex as those of the spinal cord.

When the eyelids wink at a flash of light, or a threatened blow, a reflex action takes place, in which the afferent nerves are the optic, the efferent the facial. When a bad smell causes a grimace, there is a reflex action through the same motor nerve, while the olfactory nerves constitute the afferent channels. In these cases, therefore, reflex action must be effected through the brain, all the nerves involved being cerebral.

When the whole body starts at a loud noise, the afferent auditory nerve gives rise to an impulse which passes to the medulla oblongata, and thence affects the great majority of the motor nerves of the body.

It may be said that these are mere mechanical actions, and have nothing to do with the operations which we

associate with intelligence. But let us consider what takes place in such an act as reading aloud. In this case, the whole attention of the mind is, or ought to be, bent upon the subject matter of the book ; while a multitude of most delicate muscular actions are going on, of which the reader is not in the slightest degree aware. Thus the book is held in the hand, at the right distance from the eyes ; the eyes are moved from side to side, over the lines and up and down the pages. Further, the most delicately adjusted and rapid movements of the muscles of the lips, tongue, and throat, of the laryngeal and respiratory muscles, are involved in the production of speech. Perhaps the reader is standing up and accompanying the lecture with appropriate gestures. And yet every one of these muscular acts may be performed with utter unconsciousness, on his part, of anything but the sense of the words in the book. In other words they are reflex acts.

Similar remarks apply to the act of "playing at sight" a difficult piece of music. The reflex actions proper to the spinal cord itself are *natural*, and are involved in the structure of the cord and the properties of its constituents. By the help of the brain we may acquire an infinity of *artificial* reflex actions, that is to say, an action may require all our attention and all our volition for its first, or second, or third performance, but by frequent repetition it becomes, in a manner, part of our organisation, and is performed without volition, or even consciousness.

As every one knows, it takes a soldier a long time to learn his drill—for instance, to put himself into the attitude of "attention" at the instant the word of command is heard. But, after a time, the sound of the word gives rise to the act, whether the soldier be thinking of it, or not. There is a story, which is credible enough, though it may not be true, of a practical joker, who, seeing a discharged veteran carrying home his dinner, suddenly called out "Attention!" whereupon the man instantly brought his hands down, and lost his mutton and potatoes in the gutter.

The drill had been thorough, and its effects had become embodied in the man's nervous structure.

The possibility of all education (of which military drill is only one particular form) is based upon the existence of this power which the nervous system possesses, of organising conscious actions into more or less unconscious, or reflex, operations. It may be laid down as a rule, which is called the Law of Association, that if any two mental states be called up together, or in succession, with due frequency and vividness, the subsequent production of the one of them will suffice to call up the other, and that whether we desire it or not.

The object of intellectual education is to create such indissoluble associations of our ideas of things, in the order and relation in which they occur in nature ; that of a moral education is to unite as fixedly the ideas of evil deeds with those of pain and degradation, and of good actions with those of pleasure and nobleness.

Localisation of Function in the Cortex of the Cerebral Hemispheres.—We have already alluded (p. 520) to the fact that there is a connection between particular parts of the surface of the cerebral hemispheres and particular acts or special sensations. The possibility thus indicated is of extraordinary importance and must now be dealt with in some detail.

The cerebral hemispheres are separated along the middle line of the brain by a narrow deep fissure across which the corpus callosum passes as a bridge from one hemisphere to the other (see Figs. 160 and 161). The surface of each hemisphere is folded into a large number of **convolutions** or **gyri** separated from each other by sinuous depressions or **sulci** (see Fig. 159, *C.C.*). Some of these depressions are deeper and more marked than others, and are spoken of as **fissures**. Of these the most conspicuous are known as the **fissure of Sylvius**, the **fissure of Rolando**, the **parieto-occipital fissure**, and the **calcarine fissure**. The

position of these is shown in the accompanying diagrams. These fissures may be taken as roughly dividing the surface of the brain more or less distinctly into several

FIG. 168.—DIAGRAM OF OUTER SURFACE OF THE RIGHT CEREBRAL HEMISPHERE.

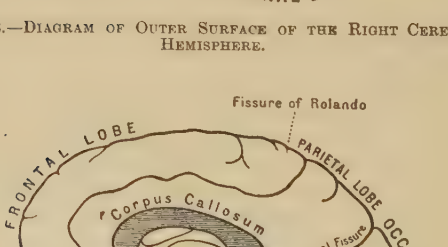


FIG. 169.—DIAGRAM OF THE INNER (MESIAL) SURFACE OF THE RIGHT HEMISPHERE TO SHOW THE PARIETO-OCCIPITAL AND CALCARINE FISSURES.

The *corpus callosum* is seen shaded in section.

lobes, **frontal**, **parietal**, **occipital**, and **temporal**. The extent of these is shown on Figs. 168 and 169.

When the surface of the hemisphere is stimulated

electrically close to the fissure of Rolando and on either side of this fissure, very definite movements take place in the limbs of the *opposite side* of the body. If care is taken to localise the stimulation as far as possible within the limits of a small area of the cortex the resulting movements are found to be limited to a correspondingly small group of muscles of the limb affected. Again, if that piece of cortex whose stimulation gives rise to movements be cut out or extirpated, the animal so operated on is found to have lost the power of executing this particular set of movements. The outcome of such experiments makes it clear that the cerebral cortex along the course of the fissure of Rolando is concerned in the development of muscular movements; hence the name of "motor areas" was given to these parts of the cortex. Our knowledge of the existence and position of these areas as derived from experiments on animals is moreover completely confirmed by the observation of the results of Nature's own experiments on man; as for instance by an examination after death of the brains of patients who during life had, as the result of cerebral disease, exhibited symptoms similar to those obtainable by stimulation or extirpation of cortical areas in animals.

Proceeding in a similar way it has been further found that certain portions of the cortex are peculiarly connected with the development of sensations, so that we come to speak also of "sensory areas." In this case observations on man are specially instructive, since the patient can give an account of his sensations, whereas another animal cannot.

One of the earliest known and most interesting cases of localisation of function in the cerebral cortex is that of the centre for speech. Some long time before experiment revealed the existence and position of the centres to which we have so far referred it was noticed by a French physician named Broca that patients who had exhibited a curious inability to pronounce definite words or syllables

during life were found after death to have suffered from disease or injury of the *third frontal convolution* of the *left*

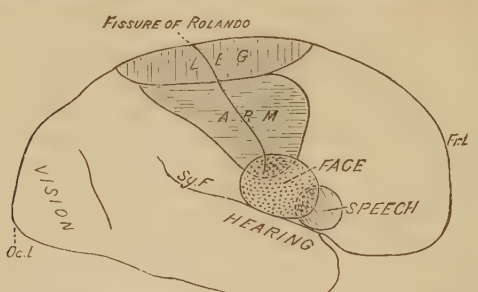


FIG. 170. DIAGRAM OF OUTER SURFACE OF RIGHT CEREBRAL HEMISPHERE TO SHOW THE POSITION OF CORTICAL AREAS.

The areas for the leg, arm, and face are marked by vertical lines, horizontal lines, and dots respectively. The area for speech lies really in a similar position on the *left* hemisphere.

Fr.L. frontal lobe; *Oc.L.* occipital lobe; *Te.L.* temporal lobe; *Sy.F.* fissure of Sylvius.

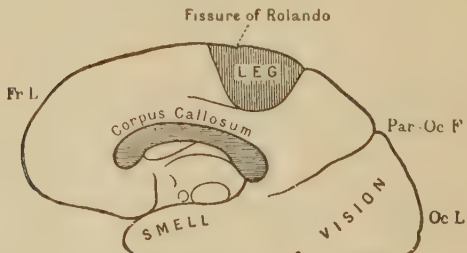


FIG. 171.—DIAGRAM OF INNER (MESIAL) SURFACE OF THE RIGHT CEREBRAL HEMISPHERE TO SHOW THE POSITION OF CORTICAL AREAS.

The *corpus callosum* is seen shaded in section.

Fr.L. frontal lobe; *Oc.L.* occipital lobe; *Te.L.* temporal lobe; *Par-Oc.F.* parieto-occipital fissure.

side of the brain immediately above the Sylvian fissure; hence, this part of the cortex is known as Broca's con-

volution (see Fig. 170). The disorder is, from its nature, known as **aphasia** (*a*, privative of, *φάσις*, speech) and may take several forms ranging from complete inability to speak at all to an inability to utter certain words, and hence to speak coherently. This centre for speech is curiously, and unlike most of the other centres, unilateral, being situated on the left side of the brain in ordinary right-handed persons and in the corresponding part of the right side of the brain in those who are left-handed.

We need say no more in proof of the connection of parts of the cerebral cortex with the development of motor impulses and the conversion of afferent impulses into those altered states of consciousness to which we give the name of sensations. The position of the parts and the uses they subserve are shown on Figs. 170 and 171.

The Internal Capsule.—The brain, as we have previously said, may be regarded as built up round a very peculiarly shaped central canal by means of thickenings of the walls of that canal due to the development of masses of nerve fibres and deposits of grey matter. We have described the position of the most conspicuous of these deposits and have incidentally referred to many of the more important inter-connections of the chief parts of which the brain as a whole consists. Moreover, we have referred in some detail to the nature of the connection of the spinal cord with the brain by means of very definite "tracts" of fibres. Among these, particular stress was laid on that tract which is known as the (crossed) pyramidal tract, and it was pointed out (p. 488) that the fibres of this tract really start in, and depend for their nutrition upon, the cells of the cortex of the cerebral hemispheres. But this dependence is not extended to the cells of the cortex generally; on the contrary it is limited to the cells of those parts of the cortex to which we applied the expression "motor areas," in the preceding section. Hence the pyramidal tract degenerates when

the cells of the "motor" areas are destroyed, and thus we come to regard the pyramidal tract as the path by which the (motor) impulses developed in the cortex are distributed to the cells of the spinal cord as a preliminary to their exit from the cord along the anterior roots of the spinal nerves. We traced the pyramidal tract into the

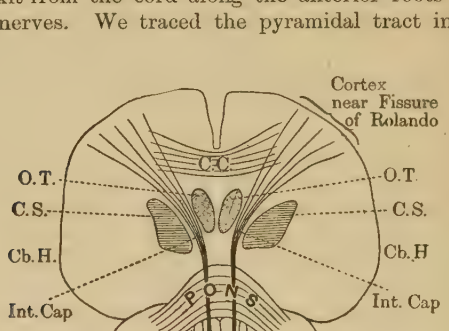


FIG. 172.—DIAGRAM OF THE COURSE OF THE CROSSED PYRAMIDAL TRACT FROM THE (MOTOR) CEREBRAL CORTEX TO THE SPINAL CORD.

C.C. corpus callosum; *O.T.* optic thalamus; *C.S.* corpus striatum; *Int.Cap.* internal capsule; *Cb*, cerebellum; *D.P.* decussation of the pyramids; *Cr.p.*, *Cr.p.* crossed pyramidal tracts (see Fig. 156); *Sp.C.* spinal cord.

bulb, and now we may, in conclusion, follow its further course until its fibres make connection with the cerebral cortex.

When this tract is traced forwards above the bulb it is found to pass into the crus cerebri of its own side and to pass along the lower or ventral part of the crus, which is known as the **pes**. The optic thalami and corpora striata are, as we have seen (p. 502), deposits on the course of the crura

as the latter sweep forward into the hemispheres. Now when the fibres of the pyramidal tract reach the level of the thalamus they *rise up out of the crus*, and, spreading like a fan, pass posteriorly between the optic thalamus and the hinder end of the corpus striatum, and anteriorly between the two parts of which the front end of the corpus striatum is composed. The fibres of the pyramidal tract as they thus pass between the optic thalamus and corpus striatum are known as the **internal capsule**, and the bend the fibres make as they rise out of the crus is known as its "knee." From this point onwards the fibres pass directly to their connections with the cells in the grey matter of the cortex along the region of the fissure of Rolando. The preceding Figure 172 shows diagrammatically the course of the pyramidal tract from the cerebral cortex to the spinal cord.

LESSON XII

HISTOLOGY; OR, THE MINUTE STRUCTURE OF THE TISSUES

1. The Body built up of Tissues and the Tissues of Cells. In the first chapter attention was directed to the obvious fact that the substance of which the body of a man or other of the higher animals is composed, is not of uniform texture throughout; but that, on the contrary, it is distinguishable into a variety of components which differ very widely from one another, not only in their general appearance, their colour, and their hardness or softness, but also in their chemical composition, and in the properties which they exhibit in the living state.

In dissecting a limb there is no difficulty in distinguishing the bones, the cartilages, the muscles, the nerves and so forth from one another; and it is obvious that the other limbs, the trunk, and the head, are chiefly made up of similar structures. Hence, when the foundations of anatomical science were laid, more than two thousand years ago, these "like" structures which occur in different parts of the organism were termed *homoiomera*, "similar parts." In modern times they have been termed *tissues*, and the branch of biology which is concerned with the investigation of the nature of these tissues is called *Histology*.

Histology is a very large and difficult subject, and this whole book might well be taken up with a thorough discussion of even its elements. But physiology is, in

ultimate analysis, the investigation of the vital properties of the histological units of which the body is composed. And even the elements of physiology cannot be thoroughly comprehended without a clear apprehension of the nature and properties of the principal tissues.

A good deal may be learned about the tissues without other aid than that of the ordinary methods of anatomy, and it is extremely desirable that the student should acquire this knowledge as a preliminary to further inquiry. But the chief part of modern histology is the product of the application of the microscope to the elucidation of the minute structure of the tissues; and this has had the remarkable result of proving that these tissues themselves are made up of extremely small *Homoiomera*, or similar parts, which are primitively alike in form in all the tissues.

Every tissue therefore is a compound structure: a multiple of histological units, or an aggregation of histological elements; and the properties of the tissue are the sum of the properties of its components. The distinctive character of every fully formed tissue depends on the structure, mode of union, and vital properties of its histological elements when they are fully formed.

2. The Primitive Tissues.—Each tissue can be traced back to a young or embryonic condition, in which it has no characteristic properties, and in which its histological elements are so similar in structure, mode of union, and vital properties to those of every other embryonic tissue, that our present means of investigation do not enable us to discover any difference among them.

These embryonic, *undifferentiated*, histological elements, of which every tissue is primitively composed, or, as it would be more correct to say, which, in the embryonic condition, occupy the place of the tissues, are technically named **nucleated cells.** The colourless blood corpuscle (Lesson III., p. 100) is a typical representative of such a cell. And it is substantially correct to say (1) that the histolo-

gical elements of every tissue are modifications or products of such cells; (2) that every tissue was once a mass of such cells more or less closely packed together; and (3) that the whole embryonic body was at one time nothing but an aggregation of such cells.

3. The Body starts as a Single Cell, the Ovum, which then divides into primitive cells.—The body of a man or of any of the higher animals commences as an ovum or egg. This (Fig. 173) is a minute transparent spheroidal sac 200μ, ($\frac{1}{120}$ of an inch) in diameter in man, which contains a similarly spheroidal mass of protoplasm, in which a single large nucleus is imbedded.

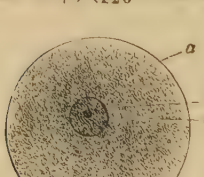


FIG. 173.—DIAGRAM OF THE OVUM.

a, granular protoplasm; *b*, nucleus, called "germinal vesicle"; *c*, nucleolus, called "germinal spot."

The first step towards the production of all the complex organisation of a mammal out of this simple body is the division of the nucleus into two new nuclei which recede from one another, while at the same time the protoplasmic body becomes separated, by a narrow cleft which runs between the two nuclei, into two masses, or *blastomeres* (Fig. 174, *a*), one for each nucleus. By the repetition of the process the two blastomeres give rise to four, the four to eight, the eight to sixteen, and so on, until the embryo is an aggregate of numerous small blastomeres, or nucleated cells. These grow at the expense of the nutriment supplied from without, and continue to multiply by division according to the tendencies inherent in each until, long before any definite tissue has made its appearance, they build themselves up into a kind of sketch model of the developing animal, in which model many of, if not all the future organs, are represented by mere aggregates of undifferentiated cells.

4. The Differentiation of the Primitive Cells.—Gradually, these undifferentiated cells become changed into groups or sets of differentiated cells, the cells in one set being like each other, but unlike those of other sets. Each set of differentiated cells constitutes a "tissue," and each tissue is variously distributed among the several

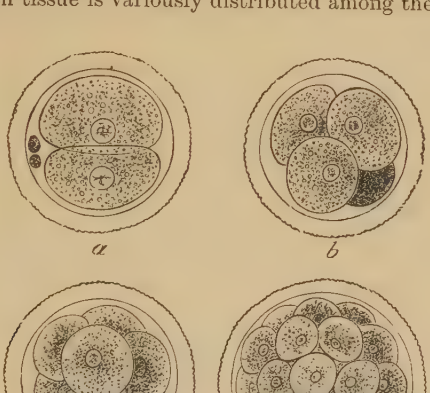


FIG. 174.—THE SUCCESSIVE DIVISION OF THE MAMMALIAN OVUM INTO BLASTOMERES. Somewhat diagrammatic.

a, division into two, *b*, into four, *c*, into eight, and *d*, into several blastomeres. The clear ring seen in each case is the *zona pellucida*, or membrane investing the ovum.

organs, each organ generally consisting of more than one tissue.

And this differentiation of structure is accompanied by a change of properties. The undifferentiated cells are, as far as we can see, alike in function and properties as they are alike in structure. But coincident with their differentiation into tissues, a division of labour takes

place, so that in one tissue the cells manifest special properties and carry on a special work ; in another they have other properties, and other work ; and so on.

5. The Chief Tissues of the Body.—The principal tissues into which the undifferentiated cells of the embryo become differentiated, and which are variously built up into the organs and parts of the adult body, may be arranged as follows.

(i) The most important tissues are the **muscular** and **nervous** tissues, for it is by these that the active life of the individual is carried on.

(ii) Next come the **epithelial** tissues, which, on the one hand, afford a covering for the surface of the body as well as a lining for the various internal cavities of the body : and, on the other hand, carry on a great deal of the chemical work of the body, inasmuch as they form the essential part of the various glandular organs of the body.

(iii) The remaining principal tissues of the body, namely the so-called **connective tissue, cartilaginous tissue,** and **osseous** or **bony tissue,** form a group by themselves, being all three similar in their fundamental structure, and all three being, for the most part, of use to the body for their passive rather than for their active qualities. They chiefly serve to support and connect the other tissues.

These principal or fundamental tissues are often arranged together to form more complex parts of the body, which are sometimes spoken of, though in a different sense, as tissues. Thus various forms of connective tissue are built up with some muscular tissue and nervous tissue, to form the blood-vessels of the body (see Lesson II.), which are sometimes spoken of as "vascular-tissue." So again, a certain kind of epithelial tissue, known as "epidermis," together with connective tissue, blood-vessels and nerves, forms the skin or tegumentary tissue ; a similar combination of epithelium with other tissues

constitutes the mucous membrane lining the alimentary canal, and also occurs in the so-called "glandular" tissue. The structure of these, as also of muscle and nerve and bone, has been already described, so that we may confine our attention here to the other principal tissues; epithelial tissues, the connective tissues and cartilage.

6. The Epidermis.—A good example of this tissue is to be found in the skin, which, as we have seen (Lesson V.), consists of the superficial epidermis which is non-vascular and epithelial in nature, and of the deep dermis, which is vascular, and is indeed chiefly composed of connective tissue carrying blood-vessels and nerves. And in all the mucous membranes there is a similar superficial epithelial layer, which is here simply called epithelium, and a deep layer, which similarly consists of connective tissue carrying blood-vessels and nerves and may also be spoken of as dermis.

If a piece of fresh skin is macerated for some time in water, it is easy to strip off the epidermis from the dermis.

The outer part of the epidermis which has been detached by maceration will be found to be tolerably dense and coherent, while its deep or inner substance is soft and almost gelatinous. Moreover, this softer substance fills up all the irregularities of the surface of the dermis to which it adheres, and hence, where the dermis is raised up into papillæ, the deep or under surface of the epidermis presents innumerable depressions into which the papillæ fit, giving it an irregular appearance, somewhat like a network. Hence it used not unfrequently to be called the **network of Malpighi** (*rete Malpighii*), after a great Italian anatomist of the seventeenth century, who first properly described it. On the other hand, its soft and gelatinous character led to its being called mucous layer (*stratum mucosum*). Chemical analysis shows that the firm outer layer of the epidermis differs from the deep soft part by containing a great deal of horny matter.

Hence this is distinguished as the *horny* layer (*stratum corneum*).

In the living subject the superficial layers of the epidermis become separated from the lower layers and the dermis, when friction or other irritation produces a "blister." Fluid is poured out from the vessels of the derma, and, accumulating between the upper and lower layers of the epidermis, detaches the latter.

The epidermis is constantly growing upon the deep or dermic side in such a manner that the horny layer is continually being shed and replaced. The "scurf" which collects between the hairs and on the whole surface of the body, and is removed by our daily brushing and washing, is nothing but shed epidermis. When a limb has been bandaged up and left undisturbed for weeks, as in case of a fracture, the shed epidermis collects on the surface of the skin in the shape of scales and flakes, which break up into a fine white powder when rubbed. Thus we "shed our skins" just as snakes do, only that the snake sheds all his dead epidermis as a coherent sheet at once, while we shed ours bit by bit, and hour by hour.

What is the nature of the process by which the epidermis is continually removed?

If a little of the epidermic scurf is mixed with water and examined under a power magnifying 300 or 400 diameters, it will seem to consist of nothing but irregular particles of very various sizes and with no definite structure. But if a little caustic potash or soda is previously added to the water the appearance will be changed. The caustic alkali causes the horny substance to swell up and become transparent; and this is now seen to consist of minute separable plates, some of which contain a rounded body in the interior of the plate, though in many this is no longer recognisable. In fact, so far as their form is concerned, these bodies have the character of nucleated cells, in which the protoplasmic

body has been more or less extensively converted into horny substance.

Thus the cast-off epidermis in reality consists of more or less coherent masses of cornified nucleated cells.

There is a yet simpler method of demonstrating this truth. At the margins of the lips the epidermis is continued into the interior of the mouth, and though it now receives the name of epithelium it differs from the rest of the skin in no essential respect except that it is very thin, and allows the blood in the vessels of the subjacent dermis to shine through. Let the lower lip be turned down, its surface very gently scraped with a blunt-

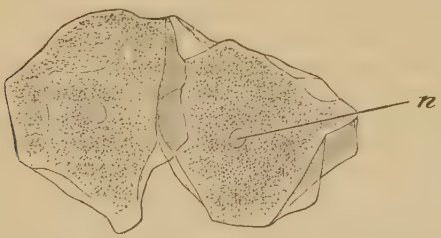


FIG. 175.—TWO EPITHELIAL SCALES FROM THE INTERIOR OF THE MOUTH.
A small nucleus *n* is seen in each, as well as fine granulations in the body of the plate. The edges of the plates are irregular from pressure. Magnified about 400 times.

edged knife, and the substance removed be spread out, and covered with a thin glass, and examined as before. The whole field of view will then be seen to be spread over with flat irregular bodies very like the epidermic scales, but more transparent, and each provided with a nucleus in its centre (Fig. 175).

Since these detached scales are always to be found on the inner surface of the lip, it follows that they are always being thrown off.

7. **The Growth of the Epidermis.**—The horny external layer of the epidermis is composed of coherent

cornified flattened cells, which are constantly becoming detached from the soft internal layer, and must needs be, in some way, derived from it. But in what way? Here microscopic investigation furnishes the answer. For if the soft layer is properly macerated it breaks up into small masses of nucleated protoplasmic substance, that is, into nucleated cells which in the innermost or deepest part of the layer are columnar in form, being elongated perpendicularly to the face of the dermis, on which they rest, and which in the intermediate region present transitions in form and other respects between these and the shed scales.

A thin vertical section of epidermis (see Fig. 57, p. 191) in undisturbed relation with the subjacent dermis, leaves not the smallest doubt (*a*) that the epidermis consists of nothing but nucleated cells, with perhaps an infinitesimal amount of cementing substance between them; (*b*) that from the deep to the superficial part of the dermis, the cells always present a succession from columnar or subcylindrical protoplasmic forms to flattened completely cornified forms. And since we know that the latter are constantly being thrown off, it follows (*c*) that these gradations of form represent cells of the deep layer which are continually passing to the surface, and being thrown off there.

What is the cause of this constant succession? To this question, also, microscopic investigation furnishes a clear answer. The deeper cells are constantly growing and then multiplying by a process of division in such a manner that the nucleus of a cell divides into two new nuclei, around each of which one half of the protoplasmic body disposes itself. Thus one cell becomes two, and each of these grows until it acquires its full size at the expense of the nutritive matters which exude from the vessels with which the dermis is abundantly supplied; such a cell in fact possesses the vital properties of a primitive embryo cell.

The cells nearer the dermis are more immediately and abundantly supplied with nourishment from the dermal blood-vessels, and serve as the focus of growth and multiplication for the whole epidermis; they are in fact the progenitors of the superficial cells which, as they are thrust away by the intercalation of new cells between the last formed and the progenitors, become metamorphosed in form and chemical character, and at last die and are cast off.

And it follows that the epidermis is to be regarded as a compound organism made up of myriads of cells, each of which follows its own laws of growth and multiplication, and is dependent upon nothing save the due supply of nutriment from the dermal vessels. The epidermis, so far, stands in the same relation to the dermis as does the turf of a meadow to the subjacent soil.

8. The Unit used in Histological Measurement.—Structures which are rendered clearly distinguishable only by a magnifying power of 300 or 400 diameters must needs be very small, and it is desirable that, before going any further, the learner should try to form a definite notion of their actual and relative dimensions by comparison with more familiar objects. A hair of the human head of ordinary fineness has a diameter of about $\frac{1}{300}$th (say 0·003) of an inch, or 0·08 mm. (millimeter). The hairs which constitute the fur of a rabbit, on the other hand, are very much finer, and the thickest part of the shaft usually does not exceed $\frac{1}{1000}$th of an inch, *i.e.* 0·001 inch, or about 0·025 mm.; while the fine point of such a hair may be as little as $\frac{1}{25000}$th of an inch, about 0·001 mm., or even less in diameter.

In microscopic histological investigations the range of the magnitudes with which we have to deal ordinarily lies between 0·1 and 0·001 millimeter; that is to say roughly between one two hundred and fiftieth and one twenty-five thousandth of an inch. It is therefore extremely convenient to adopt, as a unit of measurement, 0·001

millimeter, called a micro-millimeter, and indicated by the symbol μ, of which all greater magnitudes are multiples.[1] Thus, if the extreme point of a rabbit's hair has a diameter of 1μ, the middle of the shaft will be 25μ, and the shaft of a human head hair 80μ.

Adopting this system, the deep cells of epidermis have on an average a diameter of 12μ or more, the nuclei of 4μ to 5μ, while the superficial cells are plates of about 25μ, the nuclei retaining about the same dimensions. The diameter of a white corpuscle of the blood is about 10μ, that of a red corpuscle being 7μ to 8μ. Hence the deep cells of the epidermis are rather larger than white blood corpuscles, and the uppermost ones much larger, at least in superficial area.

9. The Epithelium of Mucous Membrane.—The mucous membrane lining the alimentary canal, as has been stated, is framed on the plan of the skin, inasmuch as it consists of a vascular dermis, and a non-vascular epithelium, the latter being composed of cells in juxtaposition. But except in the region of the mouth, where, as we have seen, the epithelium, like the epidermis, is composed of many layers of cells, arranged as a soft Malpighian layer and a hard corneous layer, and the œsophagus where the structure is similar, the epithelium of the alimentary canal and the continuations of that epithelium into the ducts and alveoli of the various glands, consists of hardly more than a single layer of cells placed side by side. Hence in a vertical section of the mucous membrane the vascular part is seen to be covered by a single row of soft nucleated cells; though sometimes a second row of inconspicuous small cells may be seen below the latter. The cells constituting this single layer vary in shape, being cylindrical or conical or, as especially in the glands, cubical or spheroidal; but they always are delicate masses of protoplasm, each containing a nucleus.

[1] Since 1 millimeter is very nearly equal to $\frac{1}{25}$ of an inch, $\mu = \frac{1}{25,000}$ of an inch.

The polygonal hepatic cells (see p. 212), are in reality the epithelium cells belonging to the minute biliary canals passing between them.

In the trachea and bronchi, the epithelium of the mucous membrane consists again of several layers of cells, but all are soft and protoplasmic nucleated masses, the uppermost layer being cylindrical in form and ciliated. In the ureter and bladder the epithelium also consists of several layers of cells which are frequently irregular in form.

Lastly, the blood-vessels and lymphatic vessels and the large serous cavities, such as the peritoneal and pleural cavities, are lined by a peculiar epithelium, different in origin from the epithelium of the skin and mucous membranes. It consists of a single layer of flat, nucleated plates cemented together at their edges. The form of the plate or cell varies, being sometimes polygonal, sometimes spindle-shaped, sometimes quite irregular (see Fig. 29).

10. **The Structure of Cartilage.**—A second group of tissues, of which cartilage may be taken as the simplest form and the type, differs from epithelium in a very essential feature. In epithelium, wherever it is found, the cells are placed close together, and the amount of material existing between the cells or *intercellular material* is exceedingly small. In the group of tissues, however, to which cartilage belongs, a very considerable quantity of intercellular material is, as we shall see, developed between the individual nucleated protoplasmic cells. Hence the cells are, more or less, distinctly imbedded in a substance different from themselves and called a *matrix*. In epithelium, though the cells are sometimes joined together by a cement material, this is never abundant enough to deserve the name of matrix.

(i) **Hyaline Cartilage.**—Characteristic specimens of this tissue are to be found in the "sterno-costal cartilages," which unite many of the ribs with the breastbone. A

thin but tough layer of vascular connective tissue invests, and closely adheres to, the surface of the cartilage. It is termed the **perichondrium**. The substance of the cartilage itself is devoid of vessels; it is hard, but not very brittle, for it will bend under pressure; and moreover it is elastic, returning to its original shape when the pressure is removed. It may be easily cut into very thin slices, which are as transparant as glass, and to the naked eye appear homogeneous. Dilute acids and akalies have no effect upon it in the cold; but if it is boiled in water, it yields a substance similar to gelatin, but somewhat different from it, which is called **chondrin**.

The sterno-costal cartilages of an adult man are many times larger than those of an infant. It follows that these cartilages must grow. The only source from whence they can derive the necessary nutritive material is the plasma exuded from the blood contained in the vessels of the perichondrium. The vascular perichondrium therefore stands in the same relation to the non-vascular cartilaginous tissue as the vascular dermis does to the non-vascular epidermis. But, since the cartilage is invested on all sides by the perichondrium, it is clear that no part of the cartilage can be shed in the fashion that the superficial layers of epidermis are got rid of. As the nutritive materials, at the expense of which the cartilage grows, are supplied from the perichondrium, it might be concluded that the cartilage grows only at its surface. But if a piece of cartilage is placed in a staining fluid, it will be found that it soon becomes more or less coloured throughout. In spite of its density, therefore, cartilage is very permeable, and hence the nutritive plasma also may permeate it, and enable every part to grow.

If a thin section of perfectly fresh and living cartilage is placed on a glass slide, either without addition or with only a little serum, it appears to the naked eye, as has been said, to be as homogeneous as a piece of glass. But the employment of an ordinary hand magnifier is sufficient

to show that it is not really homogeneous, inasmuch as minute points of less transparency are seen to be scattered singly or in groups throughout the thickness of the section. When the section is examined with the microscope (Fig. 176) these points prove to be nucleated cells, **the cartilage corpuscles**, varying in shape, but generally more or less spheroidal, sometimes far apart, sometimes very near, or in groups in contact with one another, in which last case the applied sides are flat. Usually each cell has a single nucleus, but sometimes there are two nuclei in a cell. And sometimes globules

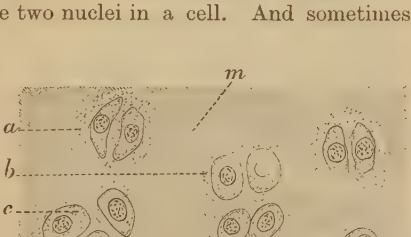


FIG. 176.—HYALINE CARTILAGE. A THIN SECTION HIGHLY MAGNIFIED.

m, matrix; *a*, group of two cartilage cells; *b*, a group of four cells; *c*, a cell; *n*, nucleus.

of fat appear in the protoplasmic bodies of the cells, and may completely fill them.

As a rule each cell lies in, and exactly fills, a cavity in the transparent **matrix**, or **intercellular substance**, which constitutes the chief mass of the tissue. But a pair of closely opposed flattened cells may occupy only one cavity, and all sorts of gradations may be found between hemi-spheriodal cells in contact, and hemi-spheriodal cells separated by a mere film of intercellular substance, and widely separate spheroidal, ellipsoidal, or otherwise shaped

cells. In size, the cells vary very much, some being as small as 10μ, and others as large as 50μ, or even larger.

As the cartilage dies, and especially if water is added to it, the protoplasmic bodies of the cells shrink and become irregularly drawn away from the walls of the cavities which contain them, and the appearance of the tissue is greatly altered.

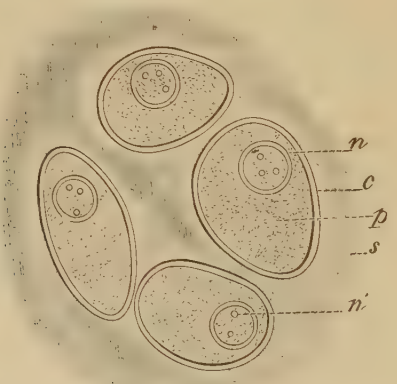


FIG. 177.—A SMALL PORTION OF A SECTION OF ARTICULAR CARTILAGE (FROG) VERY HIGHLY MAGNIFIED (600 diam.).

s, matrix or intercellular substance; *p*, the protoplasmic body of the cartilage corpuscle; *n*, its nucleus, with *n'*, nucleoli; *c*, the capsule, or wall of the cavity in which the cartilage corpuscle lies. The four cells here figured seem to have arisen from a single cell, by division, first into two and then into four. The shading of the matrix in an oblique line indicates the earlier division into two.

No structure is discernible in the matrix or intercellular substance under ordinary circumstances; but it may be split up into thin sheets or laminæ. The portions of matrix immediately surrounding the several cavities sometimes differ in appearance and nature from the rest of the matrix, so as to constitute distinct **capsules** (Fig.

177, *c*) for the cells; and, at times, the matrix may by appropriate methods be split up into pieces, each belonging to and surrounding a cell, or group of cells, and often disposed in concentric layers.

Close to the perichondrial surface of the cartilage the cells become smaller and separated by less intercellular substance, until at length the transparent chondrigenous material is replaced by the fibrous collagenous substance of connective tissue (p. 548), and the cartilage cells take on the form of "connective tissue corpuscles."

In a very young embryo we find in the place of a sterno-costal cartilage nothing but a mass of closely-applied, undifferentiated, nucleated cells, having the same essential characters as colourless blood-corpuscles, or as the deepest epidermic cells. The rudiment, or embryonic model of the future cartilage thus constituted, increases in size by the growth and division of the cells. But, after a time, the characteristic intercellular substance appears, at first in small quantity, between the central cells of the mass, and a delicate sterno-costal cartilage is thus formed. This is converted into the full-grown cartilage (*a*) by the continual division and subsequent growth to full size, of all its cells, and especially of those which lie at the surface; (*b*) by the constant increase in the quantity of intercellular substance, especially in the case of the deeper part of the cartilage.

The manner in which this intercellular substance is increased is not certainly made out. If the outermost layer only of each of the protoplasmic bodies of adjacent cells of the epidermis were to become cornified and fused together into one mass, while the remainder of each cell continued to grow and divide and its progeny threw off fresh outer cornified layers, we should have an epidermic structure which would resemble cartilage except that the "intercellular substance" would be corneous and not chondrigenous. And it is possible that the intercellular substance of cartilage may be formed in this

way. But it is possible that the chondrigenous material may be, as it were, secreted by and thrown out between the cells, as the constituents of the bile are thrown out between the hepatic cells, or at all events manufactured in some way by the agency of the cells, without the substance of the cells being actually transformed into it. Thus the capsule of each cell may be such a secretion, which then fuses into the adjacent matrix. Our knowledge will not at present permit us to form a definite judgment on this point. One thing, however, seems certain, viz. that the cells are in some way concerned in the matter; the matrix is unable to increase itself in the entire absence of cells.

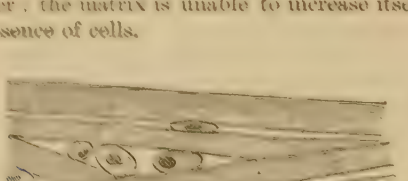


FIG. 178. — SECTION OF WHITE FIBRO-CARTILAGE. (HARDY.)

The embryonic cells, which give rise to cartilage, are not distinguishable by any means we at present possess in any respect of importance from those which give rise to epidermis.

Nevertheless, the common form must disguise a different molecular machinery, inasmuch as the two, when set going by the conditions of temperature, supply of oxygen and nutriment to which they are exposed in the living economy, work out, as their ultimate products, tissues which differ so widely as cartilage and epidermis.

The embryonic cartilage cells, like the embryonic epidermic cells, are living organisms in which certain

definitely limited possibilities of growth and metamorphosis are inherent, as they are in those equally simple organisms, the spores of the common moulds, *Penicillium* and *Mucor*. Given the proper external conditions, the latter grow into moulds of two different kinds, while the former grow into cartilage and horny plates.

(ii) **White Fibro-Cartilage.**—Since cartilage is a tissue which serves chiefly for the purposes of supporting and connecting other structures of the body, it requires, in certain positions, to be somewhat more tough and resistent, less brittle and more flexible than in others. Thus in some joints, as for instance the knee, there are little pads or discs of cartilage between the ordinary

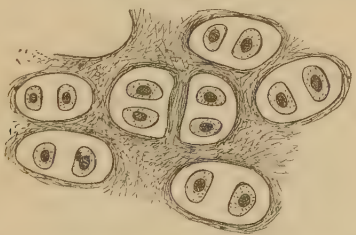


FIG. 179.—SECTION OF YELLOW ELASTIC CARTILAGE. (HARDY.)

articular cartilage (see Fig. 97, *c*). Similar discs lie in between and are attached to the bodies of the vertebræ. They act not only as a sort of cushion to break the "jar" arising from a sudden concussion of the vertebral column, but also bind the vertebræ into a column which is resistent but at the same time flexible. The additional strength required by the cartilages of these discs is provided by the introduction into their matrix of bundles of white fibrous connective tissue; hence the name, white fibro-cartilages (Fig. 178).

(iii) **Yellow or Elastic Fibro-Cartilage.**—In certain other parts of the body cartilage is required to be pecu-

liarly elastic and flexible, as in the epiglottis and cartilage of the external ear. In this case the requisite elasticity is given to it by the introduction into the matrix of a dense feltwork of fibres of yellow or elastic connective tissue (Fig. 179).

11. The Connective Tissues.

(i) **Areolar Tissue.**—If a specimen of the loose subcutaneous tissue which binds the skin to the body or of the similar tissue from between the muscles of a limb, be examined, it is found to be a soft stringy substance, which, if a small portion is carefully spread out in fluid on a glass slide and examined without the aid of any microscope, is seen to consist of semi-transparent whitish bands and fibres, of very various thicknesses, interlaced so as to form a network, the meshes of which are extremely irregular. Hence the older anatomists termed this tissue **areolar** or *cellular*.

Boiled in water, the connective tissue swells up and yields gelatin, which sets into a jelly as the water cools. After prolonged boiling, especially under pressure, it almost entirely dissolves away into gelatin, only a small filamentous solid residue remaining behind.

Dilute acids and dilute alkalies also cause connective tissue to swell up and acquire a glassy transparency, but they do not dissolve it. For if to a portion of the tissue thus altered by either acid or alkali, alkali or acid is added sufficient to neutralise the first, the tissue returns to its normal condition.

If a specimen thus rendered transparent by dilute acetic acid is examined with a magnifying glass, fine dark lines and dots are seen to be scattered through the apparently homogeneous substance. Placed under the microscope, the lines are seen to be sharply defined fibres of a strongly refracting substance. They are very elastic and are unaffected by even strong acids or alkalies or by prolonged boiling. Hence these **elastic fibres** formed a considerable part of the residue above mentioned.

The dots seen with the magnifying glass are shown by the microscope to be small nucleated cells. They are termed **connective tissue corpuscles**, just as cartilage cells are called *cartilage corpuscles*.

Thus, connective tissue resembles cartilage in so far as it consists of cells separated by a large quantity of intercellular substance; but this intercellular substance is soft, areolated fibrous, and, for the most part, either

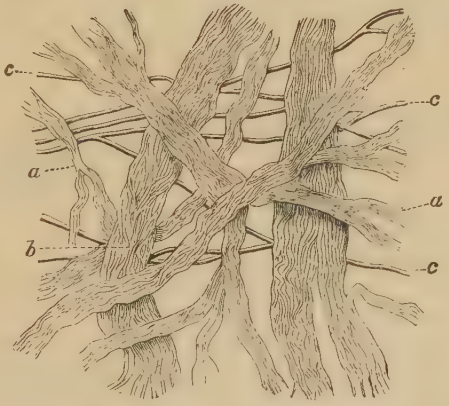


FIG. 180.—CONNECTIVE TISSUE FIBRES.

a, small bundles of white fibrous tissue; *b*, larger bundles; *c*, single elastic fibres.

collagenous or elastic, in contradistinction from that of cartilage, which is hard, solid, laminated and chondrigenous.

A specimen of fresh connective tissue prepared for the microscope in its own fluid exhibits a very different appearance. The field of view is occupied by strings or threads of extremely various thicknesses which cross one another in all directions and are often wavy. Some of the threads can be recognised as elastic by their strongly

refracting character, but the majority of them are pale and not darkly contoured. All the thicker threads and strings present a fine longitudinal striation as if they were bundles of extremely fine fibrillæ (Fig. 181, A). At intervals such bundles are often encircled by rings of a more refractive substance, and fibres of the like character may be disposed spirally round the bundles.

When dilute acetic acid is added to the specimen, the pale threads and longitudinally striated strings swell up and the longitudinal striation disappears: hence it is that the specimen becomes so transparent (Fig. 181, B). More-

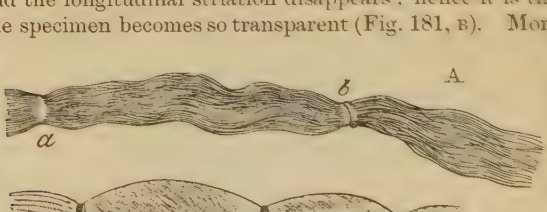


FIG. 181.

A. A small bundle of connective tissue, showing longitudinal fibrillation, and at *a* and *b* encircling (annular, spiral) fibres. Magnified 400 diameters.

B. A similar bundle swollen and rendered transparent by dilute acid. The encircling fibres are seen at *a*, *a*, *a*.

over it is these striated threads and strings which are dissolved by boiling water, and yield gelatin. We may therefore speak of them as **collagenous** or gelatin-yielding fibres, by way of distinction from the fibres of **elastic** substance, which do not yield gelatin on boiling, and are of a different chemical nature.

By various modes of maceration the collagenous fibres may be resolved into filaments which answer to the space between the striæ, and are of such extreme fineness that they may measure less than 1μ in diameter. It

would appear therefore that the intercellular substance of the connective tissue in question is composed of (*a*) **collagenous filaments**, united by some cementing substance into bundles, and of (*b*) **elastic fibres**. These latter are generally united into long meshed networks (Fig. 182).

With care, the *cells* or **connective tissue corpuscles** may also be seen even in fresh, living connective tissue (Fig. 183); but, as has been stated, they are most distinctly visible when the tissue is treated with dilute acetic acid. These cells, when seen in the fresh tissue,

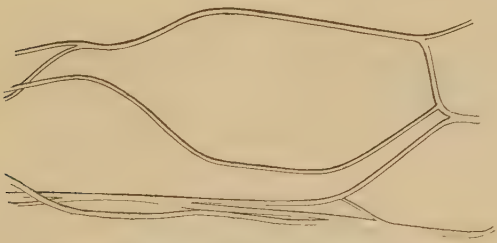


FIG. 182.—ELASTIC FIBRES OF CONNECTIVE TISSUE, FORMING A LOOSE NETWORK.

Obtained by special preparation from subcutaneous tissue. Magnified 800 diameters.

care being taken to prevent the post-mortem changes which they readily undergo, are found to be flattened plates almost like epithelial scales, but with very irregular contours. They closely adhere to, and are, as it were, bent round the convex faces of the larger bundles of collagenous fibres.

Besides these *fixed* connective tissue corpuscles as they are called, white blood corpuscles, or lymph corpuscles, or bodies exceedingly like them, are found lying loose in the fluid which occupies the meshes of the network of fibres, and appear to wander or travel through the spaces of the

network by virtue of their power of amœboid movement (Lesson III.). Such cells are spoken of as wandering or migratory cells.

Such are the characters of that which may be regarded as a typical specimen of connective tissue. But in different parts of the body this tissue presents great differences, all of which, however, are dependent upon the different relative extent to which the various elements of the tissue are developed.

Thus, (*a*) The intercellular substance may be very much reduced in amount in proportion to the cells, as is the

FIG. 183.—TWO CONNECTIVE TISSUE CORPUSCLES.

Each is seen to consist of a protoplasmic branched body, containing a nucleus. Very highly magnified.

case in the superficial layer of the dermis and some other places.

(*b*) The intercellular substance may be abundant, and the collagenous elements, with fibrils strongly marked and arranged in close-set parallel bundles, leaving mere clefts in the place of the wide meshes of ordinary connective tissue. This structure is seen in tendons and most ligaments.

(*c*) The elastic element may predominate as in certain (few) ligaments and the vocal cords.

(*d*) The fibrous or elastic elements may abound, but a greater or less amount of chondrigenous substance is developed around the corpuscles. These are respectively the **fibro-cartilages** and **elastic cartilages**, which we

ave already described and which present every transition etween ordinary cartilage and ordinary connective tissue piglottis, intervertebral ligaments). Where a tendon is serted into a cartilage, as in the case of the *tendo Achillis*, Fig. 90), the passage of the cartilage into the tendon is utifully displayed. The intercellular substance of the rtilage gradually takes on the characters of that of the ndon, and the corpuscles of the cartilage become nnective-tissue corpuscles.

(*e*) The intercellular substance may largely disappear nd the interlacing bundles of collagenous fibres may tually join together at the points when they cross one nother. In this way a spongy network of branching bres may be formed whose meshes are filled with fluid, s in the lymphatic glands.

(*f*) Finally, in many parts of the body fatty matter is und within the protoplasmic substance of the connective ssue corpuscles just as we have seen it to be formed in rtilage corpuscles.

In this way we arrive at modifications of the fundaental type of connective (areolar) tissue which are so aracteristic as to merit separate description.

(ii.) **White Fibrous Tissue.**—This form is met with in e dense and strong connective tissue of which tendons d most ligaments are composed. In these structures e collagenous fibres of areolar tissue are arranged in *nse, parallel bundles*, among which are a certain number peculiarly flattened connective tissue corpuscles, ranged in rows and now called tendon cells. The ructure of a tendon thus provides the qualities so sential to it of great strength, complete flexibility, but solute want of all elasticity or extensibility.

(iii.) **Yellow Elastic Tissue.**—This form occurs pically in the strong ligament (*ligamentum nuchae*) at the ck of the neck (see Fig. 102, *b*) which, while giving support the head, permits it at the same time to be bent rward, since the ligament is extensible. This ligament

is very highly developed in long-necked animals such as the horse. The vocal cords of the larynx are also composed of this tissue.

It consists of the elastic fibres of areolar tissue, now arranged in dense, more or less *parallel*, *bundles*. The fibres are sufficiently thick to show a well-marked outline. They also frequently branch into finer fibres, and when teased out the broken ends of the fibres are characteristically curled (Fig. 184).

FIG. 184.—ELASTIC FIBRES TEASED OUT AND MAGNIFIED ABOUT 200 DIAMETERS. (SHARPEY.)

(iv.) Adenoid, Retiform or Lymphoid Tissue.—As already described (p. 90) the functionally essential parts of a lymphatic gland are composed of this tissue, and it permeates the "pulp" of the spleen, although here it is in a somewhat modified form.

Adenoid tissue is a simple *network of branching fibres* (see Fig. 30) whose substance is nearly identical with that of the collagenous fibres of areolar tissue, but has some affinities to that of elastic tissue.

(v.) Adipose Tissue.—This tissue is the ordinary "fat" found in many parts of the body. It consists simply of areolar connective tissue in which the connective tissue corpuscles are present in vast numbers and contain neutral fat, composed of a mixture of stearin, olein and palmitin. These modified cells are held together by a vascular framework furnished by the connective tissue to which they belong.

The cells are at first indistinguishable from ordinary

nnective tissue corpuscles, but by degrees minute anules and droplets of fat appear in the cell-substance, crease in numbers, distend the body of the cell, and

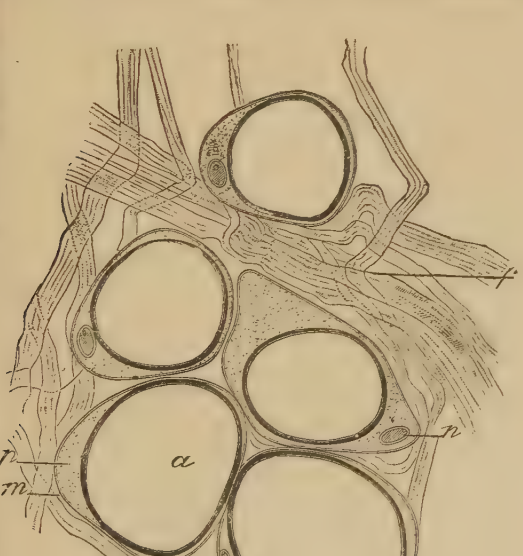


FIG. 185.—ADIPOSE TISSUE.

ve fat cells, held together by bundles of connective tissue *f*. *m*, the mbrane or envelope of the fat cell ; *n*, the nucleus, and *p*, the remains he protoplasm pushed aside by the large oil drop *a*. Magnified 200 neters.

e the place of the cell-substance. Thus finally each becomes a spheroidal sac full of fat, with the leus pushed to one side (Fig. 185).

12. The Development of Connective Tissue.—In a young embryo, the places in which connective tissue will make its appearance are occupied by masses of simple undifferentiated nucleated cells. By degrees, the cells become separated from each other by a transparent intercellular substance or matrix, which eventually takes on the form of collagenous fibrils and elastic fibres, the relative proportion and the disposition of the two varying according to the kind of connective tissue which is being formed. As in the corresponding case of cartilage, the exact part played by the cells in the formation of this matrix is still a matter of dispute. As the development of the tissue proceeds, the cells multiply by division and assume their characteristic flattened and irregular forms, applying themselves to or rather becoming compressed between the bundles of collagenous fibrils.

13. The Development of Bone.—The structure of bone has been previously and fully described (p. 310); we may now deal here with its development. Careful inspection of a transverse section of the wall of the shaft of a long bone is by itself sufficient to show that bone is constantly being formed and as constantly removed. Such a section exhibits, as has been said, a number of Haversian canals surrounded by circular zones formed of concentric layers of bone. But interspersed between these there lie larger and smaller segments of zones formed of similar concentrically curved parallel lamellæ, the so-called intersystemic lamellæ (Fig. 94, *d*), which have evidently at one time formed parts of complete Haversian systems, but which have been partially destroyed and replaced by new systems. In fact the formation of new bone is constantly taking place: (i) at the surface in contact with the periosteum; (ii) at the surface in contact with cartilage; (iii) at the surface in contact with the medulla and its prolongations in the cancelli and Haversian canals; and the bone thus formed is after a time destroyed and replaced by new growths.

To understand this we must study the origin of osseous tissue. At a certain period of embryonic life there is no bone in any part of the body. Nevertheless, the greater number of the "bones," for example the vertebræ, the ribs, the limb bones, and some of the cranial and facial bones, exist in a morphological sense, inasmuch that cartilages having the general form of such bones exist in the places of the future bones. In the place of the humerus and the femur, for example, there are rods of pure cartilage, which are, so to speak, small rough models of the humerus and femur of the adult. When the process of bone formation commences slight opaque spots, termed "**centres of ossification**," make their appearance in the substance of the cartilage, the opacity being due to the deposit of calcareous salts at these points.

Microscopic examination shows that the calcareous salts are deposited in the intercellular substance, which, therefore, is converted into a sort of bone in which the lacunæ are represented by the cavities of the cartilage corpuscles. These calcareous salts must reach the centres of ossification dissolved in the plasma which is exuded from the perichondrial vessels and permeates the intercellular substance.

In the cartilaginous rudiment of a long bone three such centres of ossification usually make their appearance, one in the centre of the shaft and one in each end. Supposing these centres to be formed at the same time (which may not however be the case), what we have to start from is a rudiment or model in cartilage of the future bone converted at three points into calcified cartilage; that is to say there is a central nodule (*diaphysis*) and two terminal nodules (*epiphyses*). If the deposit were to spread from three centres until the three nodules united the result would be a calcified cartilage in place of the formative cartilage.

As a matter of fact the deposit does spread through the rudiment from each centre outwards so long as the

bone is growing. But the cartilage between the diaphysis and epiphyses and that beyond the ends of the epiphyses also grows and increases with the general growth of the bone. That beyond the epiphysial ossification remains throughout life as articular cartilage, while that between the epiphysial and diaphysial ossifications is gradually encroached upon by these and finally obliterated.

If this were all, the adult bone would consist of calcified cartilage tipped at the ends with cartilage which remained uncalcified. But this is not all; such a mass of calcified cartilage is not a true bone. The adult femur *e.g.* consists, not of calcified cartilage, but of true osseous tissue with the characters described above, there being no simple calcified cartilage anywhere except at the junction of the articular cartilages with the subjacent bone. And the true osseous tissue of the femur has a different origin from that just described, inasmuch as it has been produced by the calcification in a special way of a peculiar non-cartilaginous tissue developed from the vascular sheath of connective tissue surrounding the original cartilage, which is at first called perichondrium, but which, as ossification goes on, receives the name of periosteum. This perichondrial or periosteal tissue in a somewhat complex manner destroys or absorbs the calcified cartilage and replaces it by true bone.

In fact, very soon after the ossific centres have made their appearance, vascular processes of the perichondrium grow into them. These processes make room for themselves by, in some way, causing the destruction and absorption of the calcified cartilage, giving rise to large irregular spaces or areolæ, which they occupy. The processes consist of blood-vessels surrounded by a peculiar form of connective tissue, characterised by the presence of large nucleated cells called **osteoplasts**. The perichondrium or periosteum from which these processes grow out has a similar structure and is also rich in osteoplasts.

No sooner have these processes hollowed out the areolæ in the calcified cartilage than they begin to line them with layers of true bone, the matrix of the connective tissue of the processes being calcified in such a way as to leave spaces in which some of the cells or osteoplasts remain imbedded, fine branching canals being left in the matrix, or being subsequently formed in it. In other words, layers of true bone, with lacunæ containing nucleated cells and with branched canaliculi, are thus constructed as a lining to the spaces hollowed out of the calcified cartilage. None of the spaces, however, are completely filled up, and there are no signs of regular Haversian systems with canals and concentric laminæ. The calcified cartilage is simply replaced by a loose open network of spongy bone, in the thickness of the bars of which may be seen the remains of the calcified cartilage, and the cavities of which are filled with blood-vessels and delicate connective tissue, that is, with marrow.

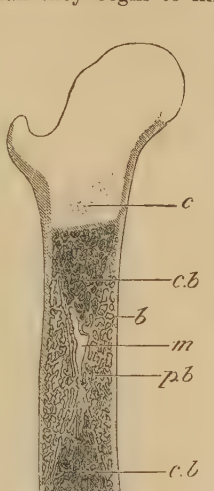


FIG. 186.—LONGITUDINAL SECTION OF OSSIFYING HUMERUS (DOG).

c, the original primitive cartilage; *c*, *b*, spongy bone arising from ossification of cartilage; this has already been absorbed and replaced by medulla at *m*; *pb*, bone (also spongy) formed by the periosteum; it is seen extending as a thin sheet upwards and downwards outside the cartilage. (Magnified 7 diameters.)

Meanwhile the perichondrium or periosteum, in addition to adding in these processes which thus convert the calcified cartilage into spongy but true bone, deposits layers of somewhat denser but still spongy bone on the

outside of the changed and changing ossific centre, in the form of a cylinder which grows in thickness by the addition of new layers on its surface, immediately under the periosteum, and in length by the extension of these

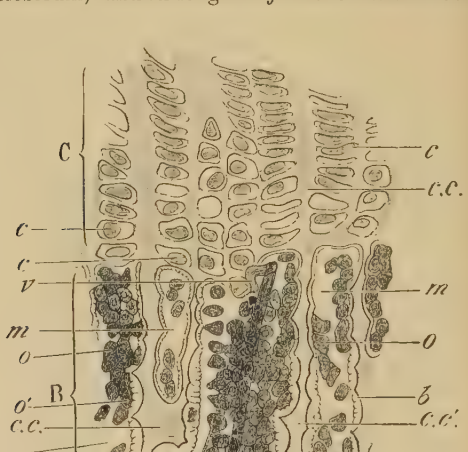


FIG. 187.—LONGITUDINAL SECTION OF OSSIFYING CARTILAGE.
C, region of cartilage; *B*, region of bone.

In *C* are seen the cartilage cells, *c*, lying in their cavities, and, arranged in columns between them, are the bars of calcified matrix *c c*.

In *B* are seen the long irregular medullary spaces *m*, containing the osteoplasts *o*, and in one is seen a blood-vessel *v*. These spaces are becoming lined with true bone, *b*, in which, as at *o'*, the osteoplasts are entangled, and the canaliculi visible. At *c c'* are seen the remains of the calcified cartilage, coated with true bone on each side.

cylindrical layers upwards and downwards. The "periosteal" bone, as this is called, is true bone, the deposition of calcic salts taking place in the matrix around the osteoplasts in such a way as to leave lacunæ and canaliculi.

Very soon after this sheath of periosteal bone has made its appearance, the spongy bone first formed in the calcified cartilage is absorbed again by the same vascular processes which formed it, so that soon what was at first the centre of ossification, after passing from simple cartilage to calcified cartilage, and so to spongy bone, is resolved into marrow or medulla, that is into vascular connective tissue richly loaded with fat.

Thus, confining our attention to the diaphysis, we may say that the primitive femur becomes cut into two halves by the substitution of vascular medulla for the primitively non-vascular cartilage. But the cartilage of each half continues to grow in length and thickness nearest the medulla, and to be successively converted first into calcified cartilage and then into spongy bone at its end nearest the medulla.

The two halves, however, are held together by the ring or cylinder of periosteal bone just described, which grows in thickness and length as the primitive cartilage of the two halves become more and more separated by calcified cartilage, spongy bone and medulla. The medulla increases rapidly until the diaphysis assumes the form of a cylinder of periosteal bone, with narrow but thicker walls in the middle, and with wider but thinner walls at each end, somewhat like a long narrow dice-box (Fig. 186). The middle of the cylinder is occupied by medulla alone, but each end is, as it were, plugged by a disc of cartilage undergoing conversion into calcified cartilage, then into spongy bone, and finally into medulla.

If we take a vertical section of one of these discs (Fig. 187), we may trace out these changes as they are taking place.

In the vicinity of its outer face the cartilage cells are undergoing rapid multiplication, and arrange themselves in columns parallel with the long axis of the bone, and therefore perpendicular to the face of the zone of calcified cartilage. Between these columns the calcified inter-

cellular substance forms partitions, so that the columnar masses of cells lie in deep honeycomb-like chambers with calcified walls.

Lower down these chambers are seen to be broken into by vascular processes of the medulla, and converted into larger irregular chambers, the walls of which are being lined with true bone, containing lacunæ and canaliculi. Still lower down the walls of these new chambers are seen to be again absorbed, until nothing is left but medulla.

As the developing bone grows the discs get farther and farther apart, and the medulla grows longer until the two ends of the diaphysis meet the epiphyses, and unite with them. The whole disc thus becomes at last spongy bone continuous with the similar spongy bone into which the epiphysis is converted, all that remains of the calcified cartilage being an exceedingly thin layer just below the articular cartilage at either end of the bone.

Thus though the primitive cartilage serves as the model of the future bone, a great deal of the bone, namely, the dense compact bone which forms the shaft and is continued as a shell over the two ends, does not come from the cartilage at all but is deposited by the periosteum; the spongy bone at each end is the only part that is formed in the cartilage, and even in that, as we have seen, there are no remains of the cartilage itself.

Moreover the bone even thus formed is subject to incessant change. The periosteal bone is at first spongy and slight in texture, and exhibits no true Haversian systems. Little by little spaces are scooped out in it by vascular processes of the periosteum on the outside and of the medulla on the inside, like those which formed it; and such a space when formed is in turn filled up in a solid fashion by layers of bone deposited in a regular way as concentric lamellæ round the blood-vessels of the process, which in the end remains as the blood-vessel of the Haversian canal, in the centre of the Haversian system

thus deposited. And indeed similar processes of absorption and fresh formation go on certainly while the bone is increasing in size, and probably also for some time afterwards.

A good many bones, such as the frontal and parietal bones of the skull, have no cartilaginous precursors. The roof of the skull of an embryo is formed of connective tissue, and the primitive centre of ossification in which one of the bones commences is a calcification of that part of the connective tissue which occupies the place of the centre of the future bone. The calcification radiates from this centre outwards, so that it soon has the form of a thin plate, the margins of which are as it were frayed out in filaments. The vascular connective tissue which incloses the plate becomes its periosteum, and plays the same part in relation to the growing bone as the periosteum of cartilage bone does to it. As the plate grows thicker, medullary processes burrow into it and give rise to cancelli and Haversian systems.

14. The Development of the Teeth.[1]—The teeth begin to be developed long before birth, and while the jaw bones are in a very rudimentary condition. The deep face of the epithelium covering the free surface of the gum thickens into a ridge, and thus depresses the corresponding face of the dermis, which at the same time grows up at the sides of the ridge. In this way a semicircular groove, which is termed the **dental groove**, is developed in the dermis of the gum of each jaw. But it must be remembered that the epithelium completely fills the groove and passes from side to side smoothly over it. Next, each groove, that in the upper jaw and that in the lower, becomes subdivided into ten pouches, five on each side of the middle line, and behind the fifth on each side there remains a residue of the groove, which may be called a **residual pouch.**

Each of the first-mentioned pouches becomes gradually

[1] The structure of a tooth has been described on p. 231.

more and more distinct from its neighbours, until at length its walls unite and shut off the epithelium which it contains from the cavity of the mouth. The result is a closed bag full of epithelium, which is a milk **tooth sac.** At the same time the dermis of the bottom of the sac has grown up as a conical process into its interior ; and this **dental papilla** is the rudiment of the future tooth. It follows that the epithelium of the sac now forms a thick cap, the convexity of which is applied to the walls of the sac, while its concavity fits accurately on the surface of the papilla.

While the milk-tooth sac is thus shaping itself, its epithelium grows out on one side into a small process, which gradually increases in size and takes on the characters of a second tooth sac. This is the sac of the **permanent** tooth, which answers to and will replace each milk tooth.

A similar change takes place in the residual pouches, each of which gradually becomes divided into three sacs for the three hindmost permanent teeth in each jaw.

The sacs of the milk teeth rapidly increase in size and become separated from one another by partitions of bone developed from the jaw with which they are in relation, and which grow up round them. They thus become lodged in alveoli.

The papilla becomes vascular, and in its central part the cells of which it is primitively composed give rise to connective tissue. At its surface it retains its embryonic characters, except that the cells become slightly elongated perpendicularly to the surface. These cells, which are termed **odontoplasts,** are separated by a delicate structureless basement membrane from the very similar cells of the epithelial cup. This is now termed the **enamel organ.** It consists of (*a*) a layer of somewhat elongated close-set cells adherent to basement membrane covering the papilla, the **papillary epithelium** ; (*b*) of a layer of less elongated close-set cells, adherent to the walls of the sac, the **parietal epithelium,** continu-

ous with the papillary epithelium at the base of the papilla ; (*c*) of **intermediate cells** which have a more or less stellate form, and adhere loosely.

The proper tooth substance first makes its appearance as a very thin hollow cap of glassy calcareous deposit at the summit of the papilla, between the layer of odontoplasts and the papillary epithelium. This cap gradually extends over the whole surface of the papilla (which has in the meanwhile taken on the form of the future tooth), and increases in thickness from the summit towards the base, so that the part of the tooth which is first formed remains, and the new tooth substance can be added only to its papillary face and to its basal margins. Hence, the increase of the tooth is accompanied by decrease of the papilla, which eventually remains in the cavity of the finished tooth as the pulp. In the region of the crown, the calcareous deposit which first takes place is extremely dense, and takes on a prismatic structure ; but in the deeper layers the deposit takes place in such a manner as to leave fine interspaces, which become the dentinal canals. The substance of the pulp has exactly the same relation to the dentinal canals as the substance of ossifying periosteal or medullary tissue has to the canaliculi, and a layer of the odontoplasts remains as the layer of cells mentioned on p. 232, as forming the superficial part of the pulp. The pulp cavity is, as it were, a gigantic lacuna containing myriads of cells instead of one.

There can be no doubt about the mode of origin of dentine. But it should be stated that in the opinion of many the enamel fibres result, not as described above, from a calcification of the papilla, but from a calcification of the cells of the papillary epithelium.

The fully formed milk teeth press upon the upper walls of the sacs in which they are enclosed, and, causing a more or less complete absorption of these walls, force their way through. The teeth are then, as it is called, **cut.**

The cutting of this first set of teeth, called **deciduous**, or **milk teeth**, commences at about six months, and ends with the second year. They are altogether twenty in number—eight being cutting teeth, or **incisors**; four, eye teeth, or **canines**; and eight, grinders, or **molars**.

It has been seen that each dental sac of the milk teeth, as it is formed, gives off a little prolongation, which becomes lodged in the jaw below the milk tooth, enlarges, and develops a papilla from which a new tooth is formed. As the latter increases in size, it presses upon the root of the milk tooth, which preceded it, and thereby causes the absorption of the root and the final falling out, or shedding, of the milk tooth, whose place it takes. Thus every milk tooth is replaced by a tooth of what is termed the **permanent dentition**. The permanent *incisors* and *canines* are larger than the milk teeth of the same name, but otherwise differ little from them. The permanent teeth, which replace the milk molars, are small, and their crowns have only two points, whence they are called **bicuspid**. They never have more than two fangs.

We have thus accounted for twenty of the teeth of the adult. But there are thirty-two teeth in the complete adult dentition, twelve grinders being added to the twenty teeth which correspond with, and replace, those of the milk set. Permanent back grinders, or **molars**, are developed in the sacs which are formed out of the residual pouches above mentioned. They have four or five points upon their square crowns, and, in the upper jaw, commonly possess three fangs.

The first of these teeth, the anterior molar of each side, is the earliest cut of all the permanent set, and appears at six years of age. The last, or hindermost, molar is the last of all to be cut, usually not appearing till twenty-one or twenty-two years of age Hence it goes by the name of the "**wisdom tooth**."

APPENDIX

ANATOMICAL AND PHYSIOLOGICAL CONSTANTS

The weight of the body of a full-grown man may be taken at 70 kilogrammes (154 lbs.).

I. General Statistics.

Such a body would be made up of—

	Per cent.	lbs.
Muscles and tendons	41	63
Skeleton	16	25
Skin	7	10·7
Fat	18	28
Brain	2	3
Thoracic viscera	2	3
Abdominal viscera	7	10·7
Blood[1]	7	10·7
	100	154·1

Or of—

Water	57	88
Solid matters	43	66

[1] The total quantity of blood in the body is calculated at about $\frac{1}{13}$ to $\frac{1}{14}$ of the body weight.

The solids would consist of the elements oxygen, hydrogen, carbon, nitrogen, phosphorus, sulphur, silicon, chlorine, fluorine, potassium, sodium, calcium (lithium), magnesium, iron (manganese copper, lead), and may be arranged under the heads of—

Proteids. Carbo-hydrates. Fats. Minerals.

Such a body would lose in 24 hours—of water, about 2,600 grammes (6 lbs. or 4½ pints); of other matters, about 940 grammes (2 lbs.), which would contain about 270–300 grammes (or rather more than ½ lb.) of carbon, 20 grammes (¾ oz.) of nitrogen and 30 grammes (about 1 oz.) of mineral matters (inorganic salts).

It could do about 150,000 kilogramme-metres (480 foot-tons[1]) of work, and gives off as much heat (2,300 kilogramme degree units) as would be able to do five times as much work again, say 850,000 kilogramme-metres (or about 2,700 foot-tons). The total energy expended by the body as heat and work (calculated entirely as work) is thus about 1,000,000 kilogramme-metres (3,180 foot-tons), of which one-sixth is expended as work and five-sixths as heat.

The loss of substance would occur through various organs and to the respective amounts shown in the table on p. 268.

The gains and losses of this body would be *about* as follows:—

Creditor:—Solid dry food .	600 grammes	(1¼ lbs.)
Oxygen . . .	640 ,,	(1½ ,,)
Water	2,300 ,,	(5¼ ,,)
	3,540 grammes	(8 lbs.)
Debtor:—Water	2,600 grammes	(6 lbs.)
Other matters .	940 ,,	(2 ,,)
	3,540 grammes	(8 lbs.)

[1] A foot-ton is the equivalent of the work required to lift one ton one foot high.

II. Nutrition.

Such a body would require for daily food, carbon 270–300 grammes, nitrogen 20 grammes.

Now proteids contain, in round numbers, about 15 per cent. nitrogen and 53 per cent. carbon, while carbohydrates and fats contain respectively 40 per cent. and 80 per cent. carbon. Hence the necessary amounts of nitrogen and carbon, together with the other necessary elements, might be obtained as follows (see p. 271):—

Proteids . . .	130	grms.	containing	20	grms.	nitrogen	70	grms. carbon
Carbo-hydrates	400	,,	,,	——		,,	160	,, ,,
Fats	50	,,	,,	——		,,	40	,, ,,
Minerals . .	30	,,	,,	——		,,	—	,, ,,
Water . .	2,300	,,						
	2,910			20			270	

This *might* in turn be obtained, for instance, from :—

Lean meat . . .	230	grammes	($\frac{1}{2}$ lb.)
Bread	480	,,	(say 1 lb.)
Potatoes . . .	660	,,	($1\frac{1}{2}$ lb.)
Milk	500	,,	($\frac{3}{4}$ pint)
Fat	30	,,	(1 oz.)
Water	2,300	,,	(4 pints)

This table, however, must be understood as being introduced for the sake of illustration only. Many other similar tables may be constructed by the use of various kinds of food.

III. Circulation.

In such a body the heart would beat about 72 times in a minute and probably drive out at each stroke from each ventricle about 100 to 125 grammes (5 to 6 cubic inches or $3\frac{1}{2}$ ounces) of blood.

The blood would probably move in the great arteries at the rate of about 12 inches (300 millimetres) in a *second;*

in the capillaries at the rate of 1–2 inches (25–50 millimetres) in a *minute*. The time taken up in performing the complete circuit would probably be about 30 seconds.

The *left* ventricle would probably establish a blood-pressure in the aorta equal to the pressure (per square inch) of a column of blood about 7 or 8 feet (2 metres) in height; or of a column of mercury 6–7 inches (150 millimetres) in height.

Sending out 100 grammes of blood at each stroke against this pressure the *left* ventricle does 100×2000 gramme-millimetres or 200 gramme-metres of work at each stroke: in 24 hours, at 72 strokes per minute, the total work done is about 20,000 kilogramme-metres. The work of the *right* ventricle is about one-quarter of that done by the left, since it works against a smaller blood-pressure in the pulmonary artery. The total work of both ventricles is therefore about 25,000 kilogramme-metres, or 85 foot-tons.

IV. Respiration.

Such a body would breathe about 17 times a minute.

The lungs would contain of residual air about 1,500 c.c. (100 cubic inches), of supplemental or reserve air about 1,500 c.c. (100 cubic inches), of tidal air 500 c.c. (20 to 30 cubic inches), and of complemental air 500 c.c. (100 cubic inches).

The vital capacity of the chest—that is, the greatest quantity of air which could be inspired or expired—would be about 3,500 c.c. (230 cubic inches).

There would pass through the lungs, per diem, about 10,000 litres (350 to 400 cubic feet) of air.

In passing through the lungs, the air would lose from 4 to 6 per cent. of its volume of oxygen, and gain 4 to 5 per cent. of carbonic acid.

During 24 hours there would be consumed of oxygen about 450 litres (16 cubic feet) or 640 grammes ($1\frac{1}{2}$ lb.);

there would be produced about the same volume (or rather less) of carbonic acid, which would contain about 225 grammes (8 ounces) of carbon. During the same time about 250 grammes (half a pint or 9 ounces) of water would be given off from the respiratory organs.

In 24 hours such a body would vitiate 1,750 cubic feet (1 cubic foot = 28·3 litres) of pure air to the extent of 1 per cent., or 17,500 cubic feet of pure air to the extent of 1 per 1,000. Taking the amount of carbonic acid in the atmosphere at 3 parts, and in expired air at 470 parts in 10,000, such a body would require a supply per diem of more than 23,000 cubic feet of ordinary air, in order that the surrounding atmosphere might not contain more than 1 per 1,000 of carbonic acid (when air is vitiated from animal sources with carbonic acid to more than 1 per 1,000, the concomitant impurities become appreciable to the nose). But for health, the percentage of carbonic acid should be kept down to half this amount or ·5 per 1000, so that the body should be supplied with at least about 50,000 cubic feet of fresh air each day. A man of the weight mentioned (11 stone) ought, therefore, to have at least 1,000 cubic feet of well-ventilated space.

V. Cutaneous Excretion.

Such a body would throw off by the *skin*—of water about 650 grammes (23 ounces or 1 pint); of solid matters about 20 grammes (300 grains); of carbonic acid about 25 grammes (400 grains) in 24 hours.

VI. Renal Excretion.

Such a body would pass by the *kidneys* –of water about 1,500 grammes or cubic centimeters (53 ounces or $2\frac{1}{2}$ pints); of urea about 33 grammes (500 grains or $1\frac{1}{4}$ oz.), and about the same quantity of other solid matters in 24 hours.

VII. Nervous Action.

A nervous impulse travels along a nerve at the rate of about 80 feet in a second in the frog, and of about 100 feet a second in man; but the rate in man varies very much according to circumstances.

VIII. Histology.

The following are some of the most important histological measurements :—

Red blood-corpuscles, breadth $\frac{1}{3200}$th of an inch, or 7 μ to 8 μ.

White blood-corpuscles, breadth $\frac{1}{2500}$th of an inch, or 10 μ.

Striated muscular fibre (very variable), breadth $\frac{1}{100}$th of an inch, or 60 μ; length $1\frac{1}{2}$ inch, or 30 to 40 millimetres.

Non-striated muscular fibre (variable), breadth $\frac{1}{4000}$th of an inch, or 6 μ; length $\frac{1}{500}$th of an inch, or 50 μ.

Nerve fibre (very variable), breadth $\frac{1}{12000}$th to $\frac{1}{2000}$th of an inch, or 2 μ to 12 μ.

Nerve cells (of spinal cord) excluding processes, breadth $\frac{1}{500}$th to $\frac{1}{250}$th or more of an inch, 50 μ to 100 μ or more.

Fibrils of connective tissue, breadth $\frac{1}{25000}$th of an inch, or 1 μ.

Superficial cells of epidermis, breadth $\frac{1}{10000}$th of an inch, or 25 μ.

Capillary blood-vessels (variable), with $\frac{1}{3500}$th to $\frac{1}{2000}$th of an inch, or 7 μ to 12 μ.

Cilia, from the wind-pipe, length $\frac{1}{3000}$ of an inch or 8 μ.

Cones in the yellow spot of the retina, width $\frac{1}{8000}$th of an inch, or 3 μ.

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